GEOLOGICAL SURVEY OF OHIO.

PRELIMINARY REPORT

UPON

PETROLEUM AND INFLAMMABLE GAS,

BY

EDWARD ORTON, STATE GEOLOGIST.

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SECTION I.—INTRODUCTION.

An Act of the Legislature, passed May 1st, 1885, made it the duty of the State Geologist to put into the hands of the Supervisor of Public Printing, ready for publication, on or before October 1st, 1885, the manuscript of a chapter on *Petroleum and Inflammable Gas in Ohio*, with suitable maps and illustrations, which chapter was to constitute a part of the volume on Economic Geology, the preparation of which was ordered by the act above named.

During the summer and autumn of 1885, however, the explorations for natural gas and oil were going on with more force than ever before in the State, and new facts in regard to their distribution were constantly coming to light in various quarters. The subjects were acquiring very much more economic importance than they had previously possessed, so that the chapter upon these subjects that was planned for the new volume on Economic Geology was found to be out of proportion and inadequate to their present and rapidly growing importance. The original chapter, in short, it was found necessary to expand into six or eight chapters in order to cover properly the new fields and the new facts. In other words, the chapter was growing to the size of a volume.

It was therefore concluded that the proper policy was to hold back this manuscript until the assembling of the Legislature in January, 1886, when the facts of the case could be stated and suitable provision could be made, if deemed best, for the publication of all the work prepared.

The attention of the Committees on the Geological Survey in both Senate and House was promptly invited to the facts here stated and immediate action was requested.

The result of the consideration of the question by the House Committee was the introduction of a bill by Hon T. F. McClure, of Vinton county, Chairman of the Committee, providing for the publication of the chapters on Petroleum and Natural Gas, under the title of Volume

VI, Geology of Ohio. The chapters submitted and which were to constitute the new volume were the following:

CHAPTER I. *The Geology of Ohio, reviewed with reference to Oil and Gas* (with a Geological Map of the State).
CHAPTER II. *The Origin and Modes of Accumulation of Oil and Gas.*
CHAPTER III. *The Trenton Limestone in Ohio as a source of Oil and Gas.*
CHAPTER IV. *The Berea Grit in Ohio as a source of Oil and Gas.*
CHAPTER V. *The Remaining Horizons of Oil and Gas in Ohio.*
CHAPTER VI. *The Macksburg Oil Field,* by F. W. Minshall.
CHAPTER VII. *Methods of Drilling Oil and Gas Wells,* by Fred. H. Newell.
CHAPTER VIII. *The Uses of Natural Gas and the Methods of Using,* by Emerson McMillin.
CHAPTER IX. *Table of Elevations above Sea level of localities in Ohio,* by Professor C. N. Brown.

The bill required that the manuscript should be delivered to the Supervisor of Public Printing on or before May 1st, 1886. It was estimated that this volume would consist of 400 to 500 pages, aside from the maps and illustrations.

The bill passed the House of Representatives with but a single opposing vote, but when it came to the Senate Committee on Geology it did not secure the same favorable regard. The Committee foresaw that the publication of the chapters on oil and gas at the present time would necessitate the publication of another volume at an early date on the remaining subjects embraced in the bill by which the preparation of the new material was provided for, and accordingly they counted it better to hold back the chapters above named until the remaining subjects could also be included. A bill embodying these provisions and fixing February 1st, 1887, as the date for the completion of the entire volume, was introduced into the Senate on May 10th, 1886, by Hon. A. W. Glazier, of Washington county, and was passed by the Senate on May 12th. The bill also required the State Geologist to prepare an abstract of the results of his investigation on oil and gas, to be ready for publication on or before June 15th, 1886, said abstract to be provided for from the appropriation of May 1st, 1885. This bill passed the House on May 15th and became a law.

The present paper has been prepared in compliance with this action. It contains some of the general statements pertaining to the subjects, and some of the more important results of the investigations of the survey for the last year. No further use will be made of the abstract herewith printed, but in subsequent publications it is expected that the chapters above referred to will find place, in which more extended and orderly discussions of these topics are contained than would be proper here.

THE ORIGIN OF THE NEW INTEREST IN NATURAL GAS.

The introduction and use of natural gas on the large scale that has been in progress in Pittsburgh for the last three years has made a profound impression upon competing manufacturing centers, especially upon the towns and cities of eastern Ohio. The cheapness of the new fuel, the economy resulting from several different factors in its use, the improvement of product in a number of lines of manufacture, all combine to give a decided advantage to the centers that have been fortunate enough to secure it, and to make competition seem almost hopeless to the towns that are without it.

In consequence, an earnest and eager search for natural gas has been begun and maintained in eastern Ohio. A large amount of money has been spent, and more is being freely spent in seeking to discover sources of gas adequate to the new demand within practical distances.

The interest awakened in the new fuel has not been confined, however, to the regions in most direct proximity to the Pittsburgh field, but north-western Ohio has also been stimulated to try the fortunes of the drill. The geological range and conditions of eastern and western Ohio are quite unlike, and inferences from one field cannot be safely carried to the other, but to many people the drilling of a well 1,000 or 1,500 feet deep in one place seems very much the same as drilling to an equal depth in any other, and conclusions as to probable results, however unwarranted, are confidently drawn. The occurrence of high-pressure gas at a depth of 1,200 to 1,800 feet in the Ohio Valley, for example, gives no warrant whatever for expecting to find high-pressure gas at the same depth in the Maumee or the Miami valleys. But fortunately, the search which was thus begun and conducted, has resulted in the discovery of a new horizon of petroleum and gas in western Ohio, which now promises to be the most valuable of our entire series.

In November, 1884, high-pressure gas was discovered at a depth of about 1,100 feet, in Findlay, Hancock county. The surface signs of gas were very obvious and abundant there, and had been noticed and recorded since the county was first settled, but the source had not been discovered nor even conjectured. It was a complete geological surprise to find the Trenton limestone, one of the most wide-spread and important strata of Lower Silurian age in North America, but which nowhere rises to the surface in Ohio, a source of gas. and later of oil in large amount and of great value. This limestone was known to be petroliferous to a small extent in Canada, it is true, and in Kentucky and Tennessee also it had been known to yield oil and gas in quantity, but it had been repeatedly tapped at various depths and at various points in Ohio "without a sign," and consequently there was nothing to warrant a geological expectation of such a discovery here. In fact, the drilling might have been done almost anywhere else, as the results are showing, without any large success. Out of scores of trials already made, there are but three or four centers of any important production so far reached in this part of Ohio. But a flame shot up from the pioneer well at Findlay that showed to the people of that entire section that a new source of light and heat and power was now available, at least to some small portions of the county.

Findlay became to northern Ohio and Indiana what Pittsburgh was to the eastern portion of the State. Her success incited every ambitious and prosperous town to send the drill to the new horizon to see what was there held in store. It so happened that two of the towns that first followed her example were successful—Bowling Green in reaching a moderate supply of gas, and Lima, in finding oil. These early successes almost exhaust the list of successes to the present time, but they greatly increased the ardor and enthusiasm of the early search throughout northern Ohio. While the work of exploration is still going forward on a large scale, the many failures that have occurred have sobered the judgment of the people to some extent, and those that drill now recognize the great uncertainty involved. They see that to secure a valuable supply of natural gas, something more than the drilling of a deep hole into the earth is essential, and all of the questions connected with the origin and accumulation of gas and oil are discussed with more interest than ever before.

ORIGIN OF PETROLEUM AND GAS.

It is not necessary to consider the origin of natural gas and petroleum separately. They have a common history. They are produced from the same sources, accumulated by similar agencies, and stored in the same reservoirs. In order of formation, petroleum is probably first. It is the more complex in composition and thus nearer to the organic world from which it is derived. Gas is the same substance on the downward road to the simplicity of inorganic compounds. No process is known by which gas is built up into oil, but the breaking up of petroleum into gaseous products is seen to be constantly going forward in nature, and it is also effected in the large way artificially.

Petroleum never exists free from gas, but it is sometimes asserted that gas is found that has no connection with petroleum. This claim is probably a mistaken one, and if the dryest gas could be followed throughout its underground reservoirs, it is altogether probable that accumulations of oil would be found along the line in every case. There is no horizon known that produces either substance to the entire exclusion of the other.

As already implied, petroleum and gas are derived from the organic world. Both vegetable and animal substances have contributed to the supplies, and these separate sources give different characters to their products, as will be presently shown. There are certain other theories in regard to the origin of petroleum, it is true, which have been advanced by eminent chemists, but which do not match at all well with the geological facts involved. These last named theories refer petroleum to peculiar decompositions and recompositions chiefly of water and carbonic acid which are supposed to be carried on at considerable depths in the earth where these substances are brought into contact with metallic iron or with the metallic bases of the alkalies at high temperatures. Never were more artificial or unverifiable theories presented for the explanation of natural phenomena, and it is surprising that they should have obtained any currency whatever. Something might be said for them, perhaps, if we had no other possible way of accounting for the facts to which they refer, but when they are compared with the theories of organic origin they have no standing-ground. The truth is, we are constantly manufacturing from animal and vegetable substances in the large way, both gas and oil that are fairly comparable in both chemical and physical characteristics, with the natural products. Further, we find vegetable substances passing by natural processes into petroleum and allied compounds, so that there is no need whatever to invent a strained and fantastic theory based on remote chemical possibilities, in order to cover the ground. These chemical theories teach that the process of oil and gas formation is a continuous one, and no reason is apparent why stocks may not be maintained from such a source even when they are drawn upon. Perhaps it is this feature that has recommended these theories more than any other. Any doctrine that gives us unwasting supplies of force is sure to be popular as long as it can find the semblance of justification, as witness the hold that the claims for perpetual motion have on the public mind.

The petroleum and gas of shales and sandstones are in the main derived from vegetable matter, and as the principal stocks are found in sandstones, vegetable matter may be said to be the chief source. The oil and gas of limestones are presumably derived from animal matter, inasmuch as the limestones themselves are known to be, in the main, a product of animal life.

The vegetation principally employed in this production is of the lower kinds, sea-weeds and other allied groups being altogether the most conspicuous elements. The animal life represented in limestone oil, and gas, is also of the lower groups. Plants may have been associated also with animal matter in the formation of limestone oil, to some extent.

HOW WAS PETROLEUM FORMED?

To the question, *how were these bodies formed out of organic matter?* there are various answers.

They are most commonly referred to the agency of distillation. Destructive distillation consists in the decomposition of animal or vegetable substances at high temperatures in the absence of air. Gaseous and semi-liquid products are evolved, and a coke or carbon residue remains behind. The "high temperatures" in the definition given above, must be understood to cover a considerable range, the lower limit of which may not exceed 400 or 500 degrees F.

Petroleum and gas on the large scale are not the products of destructive distillation. If shales, sandstones, or limestones holding large quantities of organic matter, as they often do, and buried at a considerable depth, should be subjected to volcanic heat in any way, there is no reason to doubt that petroleum and gas would result from this action. Without question, there are such cases in volcanic districts, but the regions of great petroleum production are remarkably free from all igneous intrusions, and from all signs of excessive or abnormal temperatures. All claims for an igneous origin of these substances are emphatically negatived by the condition of the rocks that contain them.

There is a statement of the distillation theory that has attained quite wide acceptance, which needs to be mentioned here. It is to the effect that these substances, oil and gas, have resulted from what is called "spontaneous distillation at low temperatures," and by low temperatures, ordinary temperatures are meant. It does not, however, appear on what facts in nature or upon what artificial processes this claim is based. Destructive distillation is the only process known to science under the name of distillation, which can account for the origin of oil or gas, and this does not go on at ordinary or low temperatures. A process that goes on at ordinary temperatures is certainly not destructive distillation. It may be chemical decomposition, but this process has a name and place of its own, and does not need to be masked under a new and misleading designation, such as spontaneous distillation. No help can come to us, therefore, from the adoption of the spontaneous distillation theory.

It seems more probable that these substances result from the primary chemical decomposition of organic substances buried with the forming rocks, and that they are retained as petroleum in the rocks from the date of their formation. It is true that our knowledge of these processes is inadequate, but there are many facts on record that go to show that petroleum formation is not a lost art of nature, but that the work still goes on under favorable conditions. It is very likely true that, as in coal formation, the conditions most favorable for large production no longer occur, but enough remains to show the steps by which the work is done.

The "spontaneous distillation" theory has probably some apparent support in the fact that must be mentioned here, viz.: that where petroleum is stored in a rock, gas may be constantly escaping from it, consti-

tuting, in part, the surface indications that we hear so much of in oil fields. The Ohio shale, for example, is a formation that yields along its outcrops oil and gas almost everywhere, but no recent origin is needed for either. The oil may be part of a primitive store, slowly escaping to the day, and the gas may be constantly derived from the partial breaking up of the oil that is held in the shales. The term "spontaneous distillation" might, with a little latitude, be applied to this last named stage, but it has nothing to do with the origin of either substance.

While our knowledge of the formation of petroleum is still incomplete and inadequate, the following statements in regard to it are offered as embodying the most probable view:

1. Petroleum is derived from vegetable and animal substances that were deposited in or associated with the forming rocks.

2. Petroleum is not in any sense a product of destructive distillation, but is the result of a peculiar chemical decomposition by which the organic matter passes at once into this or allied products. It is the result of the primary decomposition of organic matter.

3. The organic matter still contained in the rocks can be converted into gas and oil by destructive distillation, but so far as we know, in no other way. It is not capable of furnishing any new supply of petroleum under normal conditions.

4. Petroleum is, in the main, contemporaneous with the rocks that contain it. It was formed at or about the time that these strata were deposited.

THE DISTRIBUTION OF PETROLEUM AND GAS.

Contrary to a commonly received opinion, petroleum and gas are very widely distributed and very abundant substances. The drill can scarcely descend for even a few hundred feet at any point in Ohio, without showing the presence of one or both of them. The rocks of the State series can be roughly divided into three great groups—limestones, sandstones and shales. Petroleum is found abundantly in each of these groups. The per centage is small, but the aggregate is large. It is equally, or at least generally diffused throughout certain strata, while in others it is confined to particular portions or beds. An example of the first case is found in the Ohio shale. The Ohio Shale, Cleveland—Erie—Huron, of earlier reports, consists of a series of homogeneous, fine-grained deposits, black, blue and gray in color, 300 feet thick on their western outcrop in central Ohio, but more than 1,800 feet thick under cover in eastern Ohio. This entire formation is petroliferous, as is proved by an examination of drillings that represent the whole section. The black bands are probably most heavily charged. The chemist of the survey, Professor N. W. Lord, finds two-tenths of one per cent. of petroleum *as such*, present in these bands, and is certain from the nature of the processes that he was obliged to employ, that the entire amount is not reported. But, estimating the percentage to be but one-tenth of one per cent. in place of two-tenths, and calculating the thickness of the shale at its minimum, viz.: 300 feet, we find the total stock of petroleum held in the shale to be 1,560,000 bbls. to the square mile, or nearly twice as large an amount as has ever been obtained from any square mile of the Pennsylvania fields.

Of the limestones of the State, the Water lime, or Lower Helderberg limestone, is probably the most heavily and persistently charged with petroleum. Drillings taken from this stratum at a depth of 400 to 500 feet below the surface in the trial well now being sunk at Columbus, are

found by Professor Lord to have the same amount of free petroleum that the black shale contains, viz.: two-tenths of one per cent. The limestone also has the same thickness that is assigned to the shale on its outcrop, viz.: 300 feet. The figures, therefore, duplicate those already given. The total amount of oil exceeds 3,000,000 bbls. to the square mile.

All the other great limestones of our series carry petroleum, at least in certain beds. The Clinton limestone is often an oil-bearing rock, and the show of its outcrop has led to the sinking of a number of wells in search of oil, in past years. The Niagara limestone is highly bituminous in places. Asphaltic grains, films and masses constitute as much as 4 or 5 per cent. of its substance at several points in the State. The Corniferous limestone is also distinctly bituminous in some of its beds. The limestones of the Cincinnati group also carry a determinable amount of petroleum.

As for sandstones, all know that it is in them that the main stocks of petroleum have thus far been found, but there is good reason to believe that these stocks are not native in the sandstones, but have been acquired by them subsequent to their formation. This point will be considered further, under another head.

MODES OF ACCUMULATION OF PETROLEUM AND GAS.

In the accumulation of petroleum, two stages are to be noted, viz.: a primary and a secondary stage. The first is concerned with the retention of petroleum in the rocks, and might have been with equal propriety treated under the preceding head. The second stage is concerned with the origin and maintenance of the great stocks of oil and high-pressure gas, in which all the value attached to these substances lies. Both are connected with the composition of the rock series in which oil and gas are found, and the latter is also greatly affected by the arrangement and inclinations of the rock masses, or in other words, by their *structure.*

The primary accumulation of petroleum or its retention in the rocks in a diffused or distributed state, seems to be connected with the composition of the series to a great degree. The great shale formation of Devonian and Subcarboniferous ages that separates the Berea grit from the Devonian limestone, the western edge of which shale formation outcropping in central Ohio, is known as the Ohio shale (Cleveland, Erie, Huron), is unmistakably the source of the greatest accumulations of oil and gas, so far found, in the country. It holds thus far, as decided, a superiority to all other sources, as the Appalachian coal field does to all other sources of fossil fuel. The accumulation of petroleum in this great shale formation is no accident. It depends on two factors, viz.: the abundance of vegetable matter associated with the shales in their formation, which is attested by the large amount still included in them, and upon the affinity of clay for oil. The last named point is an important one. Clay has a strong affinity for oil of all sorts, and absorbs it and unites with it whenever the two substances are brought into contact. Professor Joseph Leidy made the interesting observation a number of years since, that the bed of the Schuylkill River in Philadelphia, below the gas works, was covered with an accumulation of the oily matters that are always formed in the process of gas-making. As these substances are lighter than water and float upon its surface naturally, it was at first sight hard to understand how they could have been carried to the river bed, but it was soon learned that the clay of the river water absorbed the

oils as they were floating along, and finally sank with them to the river floor. In a similar way we may suppose the primary accumulation of petroleum in the shales to have been in part accomplished. The oil set free by vegetable decomposition around the shores or beneath the waters of a sargasso sea, would be arrested by the fine-grained clay that was floating in the water, and would have sunk with it to the sea floor, forming this homogeneous shale formation that we are now considering. Sand would have no such collecting power.

The distribution of petroleum through limestone is not as easily explained, but it may be in part dependent on the presence of the same element, viz.: clay. In almost all limestones, there is a percentage of clay present, and frequently it rises to a conspicuous amount. Oil is held in both magnesian limestones and in true limestones in Ohio. The magnesian limestones are largely in excess in the series of the State, and it so happens that all of the most petroliferous strata are magnesian in composition, but this fact is probably without significance in this connection.

Petroleum distributed through shales or limestones in the low percentages already named, although the total amount held may be large, is of no economic value. Like other forms of mineral wealth, it must be concentrated by some natural agencies before it can become serviceable in any way. This brings us to consider the secondary accumulation of petroleum already referred to, by means of which all the great stocks have been formed and maintained This constitutes one of the most important subjects in the entire history of petroleum. The sources of oil and gas are very wide-spread, as has already been shown, but the concentrated supplies are few and far between. To learn the horizons and locations of these supplies is the condition of most successful operations in the production of oil and gas, and it is in this field that the most important practical applications of geology to these subjects are to be found.

OIL GROUPS.

As the experience of the last thirty years has abundantly shown, an oil or gas series always consists of two elements, viz.: a porous rock or *reservoir*, overlain by a close and fine-grained impervious rock or cover. A third element must always be added to make out the logical series, viz.: an underlying or associated source of oil and gas. It is obvious that the last named element is first in order and in importance, but for reasons already given in part, and for others that are not hard to find, practically we have less to do with it than with the two former elements. It will be borne in mind that the sources of petroleum are well-nigh universal, and also that they have no economic value, and are therefore seldom penetrated by the drill. The search generally terminates in the reservoir. The great sources of the Ohio scale are, as already implied, shales and limestones, both more or less bituminous. These sources have done their work wherever large accumulation is found, and where no accumulations exist the petroleum occurs, as already shown, in large but valueless stocks distributed through the body of the strata.

THE RESERVOIR.

The reservoirs must be porous rocks. In all of the experience in the great fields of Pennsylvania and New York, the rocks in which the large

stocks of oil and gas were found were, without exception, sandstones or conglomerates. To them the driller early gave the name of "oil sands," and this name is in universal use. The grain and thickness of these sandstones are found to be important factors in their production. Other things being equal, the coarser the grain and the thicker the stratum, the greater is its production found to be. Mr. J. F. Carll, of the Pennsylvania Geological Survey, our highest authority in regard to petroleum production, has shown that an oil sand can hold one-tenth of its bulk of oil, and he believes that it may contain under pressure as much as one-eighth of its bulk. This would give 1½ inches of oil to every foot of the oil sand.

Taking the most productive portions of the latter in the Venango field to be 15 feet, we find in that district a possible capacity of 9,600,000 barrels per square mile, an amount, it is needless to say, vastly in excess of any production ever known.—(2d Penna. Survey, Oil Regions, III, pp. 252–53.)

The driller places great reliance on the oil sand, and learns to draw conclusions and make forecasts from its character more than from any other single element that he encounters.

It has been a great geological surprise to find, as we have found in Ohio within the last two years, a reservoir of high-pressure gas and large oil wells in a rock of altogether different character from the oil rocks already described. The new oil and gas rock of northwestern Ohio is a magnesian limestone of ordinary type. The driller, all of whose traditions as a rule are derived from the eastern oil field, cannot call the new oil rock by any other name than the familiar one which has satisfied all of his experience hitherto, viz.: an oil sand. Accordingly, good Trenton limestone, pure enough to be burned for lime in many instances, is styled the *oil sand*, and the old standards of judgment, applicable to sandstones alone, are applied to the new rock. Its grain is discussed, when, strictly speaking, it has no grain. Some separate the upper productive belt from the underlying rock, calling the upper only the oil sand, and recognizing that which is found below as Trenton limestone. This is a distinction without a difference. There is no sandstone of any sort within 500 feet on either side, above or below, the gas rock of Findlay or the oil rock of Lima (which are one and the same thing), so far as explorations to the present time have shown. The gas rock and oil rock are in many instances exceptionally pure magnesian limestones. The structure of the rock, as shown by good-sized fragments brought up from the wells after the use of torpedoes, or sometimes by the pressure of the escaping gas, shows the rock to be moderately porous. Its porosity is due to the interlocking of its crystalline growths. If the rock is drilled small, there is nothing to show this porous character or the absence of it, and all inferences from the appearance of such drillings or oil sands, as they are styled, as to the productive power of the rock, are deceptive. They have no basis in fact. There need be no long argument over the composition of the oil rock. Sandstone does not dissolve in the ordinary mineral acids, while limestone does. If any one wishes to settle for himself the character of the oil rock of the new field, let him expose it to the action of dilute hydrochloric (muriatic) acid, which can be obtained at any drug store. Magnesian limestones do not dissolve as promptly as calcareous limestones, but with time enough they are decomposed. The following analysis (1) shows the composition of the oil rock, as brought up in a large fragment from the Woolsey well in Lima. The composition of the drillings of the oil rock from another well, in the same town, are also given in the table (2):

	1	2
Carbonate of lime	55 90	52.66
Carbonate of magnesia	38.85	37.53
Alumina and iron	2.94	....
Silica	.75	....

The first well is a small producer, in fact, is nearly a failure; the second is one of the productive wells of the field.

In the case of the new oil field, the reservoir is apparently continuous with the source of the oil. The source seems to be the entire rock, as the drillings from all depths are often found to be petroliferous, but the accumulation takes place in the upper beds only.

Besides sandstones and limestones, shales also serve to a small extent as receptacles of accumulated oil and gas in Ohio, The character of the containing rock in these cases is not well known. Generally, the gas is of light pressure, but it is a fairly persistent supply that is found in these rocks. The belt of shales along the shore of Lake Erie gives the examples of this sort of accumulation and supply. These shales, where productive of gas, are found to consist of hard and light-colored bands, interstratified with dark bands, the gas appearing to be found when the harder bands are penetrated. The production of oil from these sources is always small, but as already stated, fair amounts of gas are sometimes derived from them.

Petroleum and gas are not the only substances that are found in these reservoirs. Salt water is almost an invariable accompaniment of both. The oil rocks are salt rocks as well, in some parts of their extent. The distribution of these three substances in the same stratum is connected with facts of structure, as will presently be shown. These reservoirs have been described as porous of necessity. The porosity insures a large amount of lateral permeability, a fact of great importance in the distribution of these substances. The reservoir is often common for large areas. All the wells in a field find the same pressure of gas or oil, even though their production may be very unequal.

THE COVER.

Inasmuch as the three elements, source, reservoir and cover, are all indispensable, it is not necessary to compare their relative importance. It is, however. true that the first and second conditions of accumulation are met more frequently than the third. The cover of every productive oil rock is a large body of fine-grained, impervious clay shale—the finer and more nearly impervious the better. Whenever such a body of shale is found in the Ohio scale, the rock directly underlying, if a sandstone or limestone, is found to contain, in some portions, accumulations of gas and oil. The stocks may be too small to be valuable, but the presence of the shale cover seems to ensure some concentration in these situations. There are three points in the Ohio series of rocks where such shale covers occur, viz.: at the surface of the Trenton limestone, where 800 to 1,000 feet of shales and intercalated beds of limestone of the Medina, Hudson River, and Utica epochs are found, at the surface of the Corniferous lime-

stone, which is covered by 300 to 1,800 feet of the Ohio shale, and at the surface of the Berea grit, which is overlain by the best cover of the entire series, viz.: the close-grained and nearly homogeneous Cuyahoga shale, 300 to 500 feet in thickness. Two of these, the first and the last, constitute the two main horizons of oil and gas in Ohio. The third is not notably productive thus far in Ohio, but it is the source of the oil supply of western Canada.

The composition of an oil-producing series is thus seen to be essential to its functions. The order already pointed out cannot be departed from, but there must always be—1, an impervious cover; 2, a porous reservoir; and underneath the reservoir the source is to be found.

STRUCTURE AS AFFECTING OIL AND GAS ACCUMULATION.

But this order of arrangement is not enough in itself to ensure any large concentration of oil or gas at any particular place. One other factor must be introduced, viz.: *structure.* The strata which constitute the geological scale of the State nowhere lie, for any considerable extent, in horizontal planes. They are all more or less inclined. Sometimes they are bent into low folds or arches, and sometimes, though very rarely, there are abrupt descents and fractures. As a rule the dip, or angle of inclination to the horizon, of Ohio rocks is very small. It is better expressed as a fall of so many feet to the mile, than by angular measurements, which very seldom rise to one degree. Both the rate and the direction of the descent are uniform over large areas. The average dip for important portions of the State, is between 20 and 30 feet; the direction depends, of course, upon the part of the State which is to be considered.

The movements of the strata here referred to have exerted a very important influence on the concentration of oil and gas in the reservoirs already described. If one of these sandstone strata, filled with salt water, oil and gas, and freely permeable laterally and horizontally for even miles at a time, were to be thrown into a system of low folds, what effect would this movement have upon the contents of the stratum? Would not a separation of gas, oil and water be sure to follow, the gas finding its way to the summits of the arches, and the salt water sinking to the bottoms of the troughs? Such a result would be inevitable under the conditions assumed.

The summits of the folds are called anticlinals, and the troughs synclinals. The lines of direction of the anticlinals are called their axes. The influence of these facts of structure on gas and oil accumulation has been long recognized, or at least asserted, but there is not full agreement as to the part that it plays in the great fields among the geologists who have given most study to the subjects. Professor I. C. White, of Morgantown, W. Va., has recently formulated a theory as to the occurrence of the large stocks of natural gas, which is known as the anticlinal theory of gas. He holds that the theory is susceptible of application to all gas territory, and that it can be made to render practical service of great value by pointing out localities in which drilling may be successful, and especially by indicating the large districts where, from the nature of things, it must be fruitless. The latter service he counts the more important, as large expenditures are going on at random throughout the field, from which nothing can be reasonably expected.

The discussion of these subjects at the present time is giving us a large amount of valuable literature.

All who are engaged in the discussion recognize structure as one of the factors in oil and gas production, but some geologists, as Ashburner and Carll, apparently relegate it to a secondary place, counting the facts treated of under the previous head, viz.: the composition of the series, of more importance in this connection. The character and thickness of the strata in which the gas and oil are contained, the nature of the supply from which their stocks are derived, factors like these are considered by them of more moment than the angles at which the strata lie.

The facts that have come to light in the recent investigations of these subjects in Ohio, seem to show the paramount influence of structure upon oil and gas accumulation. In the old fields and in the new alike, irregularities of dip, involving change of direction, suspension, or unusual increase, have been found connected with the large production of both oil and gas in every instance where careful examination has been made. The composition of the series involved is identical for many thousand square miles, but so long as uniformity of dip is maintained, there is no valuable accumulation. As soon, however, as this uniformity is broken in upon, the valuable stocks of gas and oil come to light.

The "belt lines," in which the practical oil well driller and operator of the main field puts so much confidence, so far as they stand for facts in nature, are probably structural lines. A map of the various centers of petroleum in the old field shows that they all extend in the north-easterly course which the main structural features of this part of the continent follow. The driller believes fortune to lie in the 45° or 22½ line which leads out in a northeast or southwest direction from each center of production. Experience justifies, to a certain extent, his confidence. The productive gas territory upon which Pittsburgh now depends, is limited to the summits of a few well-marked anticlinals, which all have a northeasterly trend. In regard to the latter, question can scarcely be raised. The predominant influence of structure is obvious. It seems probable that a careful enough system of measurements will show like lines of modified dip to traverse the great oil fields of Pennsylvania and New York.

The occurrence of gas and oil in almost all rocks that have a heavy shale cover would seem to result from exchanges affected by gravity. The oil is associated with salt water in the stratum that contains it. There would be a constant tendency for the oil to reach a higher level at the expense of the water. It ascends through all the substance of the rock until it reaches the impervious roof, where it is gradually concentrated. On the same principle, the separation of the gas from the oil is effected.

Some of the points that have been made under this head may be briefly restated, as follows:

1. Clay is largely connected with the primary accumulation of petroleum. The natural affinity that it has for substances of this class would lead to its combination with them wherever found. The great shale formation of eastern Ohio, New York and Pennsylvania, is the main source of the petroleum and gas of these regions. Clay does its work in this regard by reason of its chemical constitution.

2. As clay is the main agent in the primary accumulation of petroleum, sand takes a similar place in its secondary accumulation, or its concentration in valuable stocks. It does this by virtue of its physical character. A sandstone is a porous rock. Such sandstones as are found overlying or imbedded in the great shale formation are sure to become receptacles of oil.

3. Clay has another office in this connection to perform, and this office is dependent on its physical character. The sandstone stratum last described, would become a *receptacle* of oil in any case, but if roofed with a sufficient thickness of clay shale by which its contents could be sealed and preserved, it would become a *reservoir* of oil or gas. All of the stocks of the old fields are held in sandstone or conglomerate reservoirs.

4. Limestone has been found, more clearly in Ohio, perhaps, than elsewhere, to replace sandstone in oil accumulation. All the phenomena of high pressure stocks of oil and gas have recently been found in the Trenton limestone of northern Ohio, but the presence and office of the shale cover are seen to be the same here as in the other fields. The term limestone in this connection is used with due care and precision. It is limestone, not "oil sand" in the limestone, that contains Findlay gas and Lima oil. Pure limestone is the driller's "oil sand" in these fields.

5. Widely diffused as are oil and gas in the paleozoic rocks of Ohio and adjacent States, so wide that the distribution of them may, without error, be styled universal, and widely extended as are the series of rocks that afford in their composition and relations the proper conditions for storage, it is still seen that their accumulation in profitable quantity depends on what might be called geological accidents. It is only, or mainly along lines of structural disturbance that the great stocks are found.

SECTION II.—THE GEOLOGICAL SCALE OF OHIO.

No description of the occurrence of petroleum and gas in Ohio can be made fully intelligible unless the geological order and structure of the State are held firmly and distinctly in mind. Unusual interest exists in these subjects at the present time, and knowledge in regard to them is eagerly sought on all sides. The expositions of the geology of Ohio given by Newberry, in Volumes I and II of the reports of the survey are not now available to many who are seeking, for the first time, information on this subject, and, lucid and admirable as his statements are, they do not meet all the questions which the developments of the last few years have raised, and which these same developments have helped us in many cases to answer, at least in part.

A brief and somewhat elementary review of the scale and structure of the State will here be given, in order to meet as fully as possible these new demands for geological information. A few fundamental facts pertaining to the subject will be stated before this review is entered upon.

1. So far as its exposed rock series is concerned, Ohio is built throughout its whole extent of stratified deposits, or in other words, of beds of sand, clay and limestone, in all their various gradations, that were deposited or that grew in water. There are in the Ohio series no igneous nor metamorphic rocks whatever—that is, no rocks that have assumed their present form and condition from a molten state, or, that subsequent to their original formation, have been transformed by heat. The only qualification which this statement needs, pertains to the beds of drift by which a large part of the State is covered. These drift beds contain bowlders in large amount, that were derived from the igneous and metamorphic rocks that are found around the shores of Lakes Superior and Huron, but these bowlders are recognized by all, even by the least

observant, as foreign to the Ohio scale. They are familiarly known as "lost rocks," or "erratics."

If we should descend deep enough below the surface, we should exhaust these stratified deposits and come to the granite foundations of the continent which constitute the surface rocks in parts of Canada, New England and the West, but the drill has never yet hewed its way down to these firm and massive beds within our boundaries.

The rocks that constitute the present surface of Ohio were all formed in water, and none of them have been modified and masked by the action of high temperatures. They remain in substantially the same condition in which they were formed.

2. With the exception of the coal seams and a few beds associated with them and of the drift deposits, all the formations of Ohio grew in the sea. There are no lake or river deposits among them, but by countless and infallible signs they testify to a marine origin. The remnants of life which they contain, often in the greatest abundance, are decisive as to this point.

3. The sea in which, or around which they grew was the former extension of the Gulf of Mexico. When the rocks of Ohio were in process of formation, the warm waters and genial climate of the Gulf extended without interruption, to the borders of the great lakes. All of these rocks had their origin under such conditions

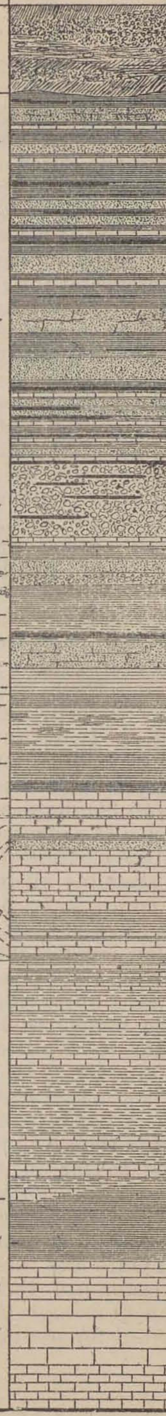
4. The rocks of Ohio constitute an orderly series. They occur in widespread sheets, the lowermost of which are co-extensive with the limits of the State. As we ascend in the scale, the strata constantly occupy smaller areas, but the last series of deposits, viz.: those of the Carboniferous period, are still found to cover at least one-fourth of the entire area of the State. Some of these formations can be followed into and across adjacent States, in apparently unbroken continuity.

The edges of the successive deposits in the Ohio series are exposed in innumerable natural selections, so that their true order can generally be determined with certainty and ease.

5. For the accumulation and growth of this great series of deposits, vast periods of time are required. Many millions of years must be used in any rational explanation of their origin and history. All of the stages of this history have practically unlimited amounts of past time upon which to draw. They have all gone forward on so large a scale, so far as time is concerned, that the few thousand years of human history would not make an appreciable factor in any of them. In other words, five thousand years or ten thousand years make too small a period to be counted in the formation of coal, for example, or in the accumulation of petroleum, or in the shaping of the surface of the State through the agencies of erosion.

The geological scale of the State is represented in the accompanying diagram. The order of the series is, of course, fixed and definite, but the thickness assigned to the several elements depends upon the location at which the section is taken. The range is generally indicated, but in any case it will be stated in explicit terms in the description of the several formations that is to follow. Two of the elements named, viz: the Oriskany sandstone and the Salina shales, are marked by an interrogation point. It is an open question whether these epochs are distinctly represented in Ohio.

VERTICAL SECTION OF THE ROCKS OF OHIO



SYSTEMS		SERIES		THICKNESS FEET
QUATERNARY	18	Glacial Drift (0' to 300')		300'
CARBONIFEROUS	17	Upper Barren Coal Measures		300'
	16	Upper Productive Coal Measures		200'
	15	Lower Barren Coal Measures		500'
	14	Lower Productive Coal Measures		250'
	13	Conglomerate Series		250
	12	Sub-Carboniferous Limestone		25
	11	Waverly Series (500' to 800')	11e Logan Series (Shale, Sandstone, Conglomerate)	500'
			11d Cuyahoga Shale	
			11c Berea Shale	
			11b Berea Grit	
			11a Bedford Shale	
DEVONIAN	10	Ohio Shale 300' to 1800'	10c Cleveland Shale	300'
			10b Erie Shale	
			10a Huron Shale	
	9	Hamilton Shale		25'
	8	Corniferous Limestone - 75' to 175'		
	7	(Oriskany Sandstone ?)		75'
UPPER SILURIAN	6	Lower Helderberg Limestone, Waterlime 50' to 300'		50'
	5	(Salina Shales ?)		30
	4	Niagara Series	4d Hillsboro Sandstone	
			4c Guelph Limestone	150'
			4b Niagara Limestone	50'
			4a Niagara Shale including Dayton Limestone	100'
	3	Clinton Limestone		50'
	2	Medina Shale		25'
LOWER SILURIAN	1	Cincinnati Series (Hudson River, Utica in part)		800'
		Lowest rocks that appear at surface		
		Utica Shales 200' to 300'		200'
		Trenton Limestone	Galena	
			Trenton	550'
			Birdseye	

THE TRENTON LIMESTONE.

Through the revelations of the drill during the last year or two, we have been obliged to add a new formation to the geological series of Ohio. We begin the series now with the Trenton limestone. It is by no means true that we were ignorant of its presence before these drillings were undertaken and that we have just learned that it underlies the State. The fact that it belongs at the bottom of the Ohio column has been clearly understood since the geological age of our lowest rocks was first determined, and the relations of these lowest rocks to the Trenton have been discussed at length by many students of our geology. But by means of the drill this great formation has suddenly acquired a large practical and economic interest. Though it nowhere rises to the surface within the limits of the State, we now know its chemical composition, its color, its hardness, its porosity, as well as we do the like qualities of limestones that make our surface rocks for thousands of square miles. Its name has become more familiar, and is spoken more times in a day by more people than that of any other of these great strata. The mineral wealth in the shape of gas and oil that it is yielding is already of great value, and every day is adding to this value.

The Trenton limestone as it occurs in outcrop in New York, Canada and Wisconsin, has been divided into two or more divisions. At the west, its uppermost beds are called the Galena limestone, the lead ore or galena of Illinois and Wisconsin being found in these beds. At the east, its bottom portion is termed the Birdseye limestone, from the occurrence of crystalline grains of calcite through the substance of the rock. This last named phase occurs in Ohio. From the deepest drillings at Findlay, fragments brought up by the pump showed the birdseye feature distinctly. It is, however, the uppermost portion in which the economic interest of the Trenton in Ohio is found.

The drill has gone down through 550 feet of limestone rock in one instance in Ohio, below the oil and gas rock, viz.: in the first well at Findlay, and aside from changes of color, and from the occurrence of the crystalline particles just named, no hints of division could be drawn in it. It probably all belongs to this age.

It comes nearest to the surface in the valley of the Ohio, in the southwestern corner of the State. It is probably between 200 and 300 feet below low water in the Ohio, or about 200 feet above sea level. It can be followed by the recent borings to the shore of Lake Erie, dipping slowly and quite equably to the northward, its surface at Toledo, for example, being found 800 feet below sea level. To the northward, it rises in the Manitoulin Islands; to the southward from the Ohio River, it rises in the Blue Grass lands of central Kentucky.

It is a magnesian limestone of a fair character throughout most of its extent. It is found somewhat silicious in some of the drillings.

Aside from its probable presence in the deep well at Cleveland, it is confined so far to the western half of Ohio. The drill has never gone down deep enough to find it in the eastern half of the State, but there is no assurance that it is to be found there in any case as a limestone. In the deep trough of the ancient gulf which is now occupied by eastern Ohio and the adjacent parts of Pennsylvania and West Virginia, the limestone of the northern border and of the other regions named might well enough be replaced by a very different formation. There is no warrant for assuming its universality as a limestone.

THE UTICA SHALE.

In the New York section, from which most of our geological names are derived, the Trenton limestone is directly overlain by a mass of dark, sometimes black shale, which, from its occurrence in good exposures about Utica, has been named from this place. In New York it is about 300 feet thick. It has but few fossils, but fortunately some of them are characteristic—that is, they have never been found in any other formation. It contains quite a notable amount of organic matter, ranging as has been asserted, from 8 to 17 per cent. This organic matter is apparently of animal, rather than of vegetable origin.

The only part of Ohio where the Utica shale is due as a surface rock, is in the southwestern corner, but the beds found here that would come in on this horizon are not dark in color, but are calcareous rather than bituminous, and although they contain some of the fossils that are found in the Utica at the east, they also contain many others. Moreover, it is impossible to draw a firm or natural boundary line between the beds that should be Utica shale and those that overlie them.

On this account, most of the geologists who have worked upon this portion of the series, have counted it best to merge the overlying beds with those that are probably of the age of the Utica, in a single formation named the Cincinnati group. These overlying beds are known as the Hudson River series in New York.

But when drilling began in Findlay in 1884, it soon became evident that the New York section could be followed intact and distinct into northern Ohio. There was a mass of dark, nearly black shale, about 300 feet in thickness, immediately overlying the Trenton limestone. The color and position of the deposit were sufficient to determine its age, but better than this, in some of the chips that were brought up, the most thoroughly characteristic fossils of the Utica shale of New York were found. Notable among these was an almost microscopic shell, *Leptobolus insignis*, that is counted by Hall and Whitfield as the best mark of the formation. It was this determination, indeed, that served to show the real name and place of the oil rock, or in other words, the Utica shale was the first of the new elements to be referred positively and definitely to its place in the general scale.

The Utica shale can be followed as far south as Springfield and Piqua as a dark shale, but it is growing more calcareous and more fossiliferous as it is traced southward. In the Ohio valley, as already stated, the boundary between it and the overlying beds becomes indistinct or is obliterated.

1. THE CINCINNATI SERIES.

This series is equivalent, as just shown, to the Hudson River and Utica formations of the general scale. It embraces the lowest rocks that find their way to the surface at any point in the State. It occupies about 4,000 square miles as a surface rock in southwestern Ohio. It consists of interstratified sheets of limestone and fine-grained shale, called clay. Both are light blue or gray in color, as a rule. The limestone and shale alike are charged with fossils in an excellent state of preservation. These beds are famous, in fact, for the large amount and the excellent preservation of the fossils of this period. The limestone and shale occur in varying proportions in different parts of the series. In the upper

portion, the limestone is in larger amount than the shale, and the whole mass is sometimes counted limestone rock.

It does not allow the surface water to descend into it, and it is consequently poor in springs and makes dry drilling.

In the northern part of the State, the upper part of this formation is known only by the well records, and by the drillings brought up from below. It is found here to be much less calcareous and much less fossiliferous than in its outcrops at the southward, though both lime and fossils are abundant in it. It is bluish green in color, and is often known as the green shale. It has a thickness of 500 to 600 feet. It corresponds well with the Hudson River rocks of New York, in all essential particulars. The fossils found in the drillings are, in some cases, identifiable, and when so, are found to be characteristic of the formation.

2. THE MEDINA SHALE.

This is another element of the New York scale that could never be positively identified in the Ohio column until the recent explorations in northwestern Ohio. It is well characterized by its position, by its color, by its composition, and it may be added, by the absence of fossils. The formation is almost everywhere poor in the traces of life, either animal or vegetable. In coming westward from New York, it has changed somewhat in composition. In New York, it consists largely of shale, but intercalated in the shale at two points, there are found very valuable beds of quarry stone. This sand is mainly lost in the Ohio sections, though in the uppermost beds there are sometimes thin courses. The color of the formation is characteristic, a light red being the prevailing tint. This mark alone would go far to identify it, as we have no red rocks in this part of the scale, except in the Medina and the associated rocks of the Clinton. It is not, however, red rock in all parts of Ohio, and probably where red rock occurs we should refer shales of other colors to the Medina if we had full opportunities for examination. The thickness of the formation as determined by the color, ranges from 30 to 90 feet in northern and central Ohio. In the southern part of the State where its outcrops occur, it is seldom more than 25 feet thick. The red band of these outcrops was long ago referred to this horizon, but its direct continuity with the rocks of the typical section could not be affirmed until the line of borings from southern Ohio to the lake completed the connections.

The Medina contains no red rock in the Lima field, but a belt of "greenish shales, gravel and sand," as described by the drillers in some wells of this region may possibly represent it. The question is, whether this belt belongs to the Medina or to the Clinton, as the latter formation sometimes includes deposits of this character. There are blue shales immediately below, that can well enough represent the Medina in whole or in part. The oil and gas wells of northern Ohio are mainly cased at this point in the scale, no further interruption frcm water being experienced in descending 800 to 1,000 feet.

3. THE CLINTON SERIES.

This series occupies a well marked interval, having the Medina shale below it and the Niagara shale for its upper boundary. The only outcrops of the formation are found in southwestern Ohio, and here the whole series consists of limestone beds that are very definitely characterized.

In northern Ohio, as the drill has shown, there is a probability that certain shale deposits found above the red Medina may belong to the Clinton age.

The Clinton limestone in its outcrops is a highly crystalline, uneven-bedded, very fossiliferous limestone. It tends to high colors, white, pink, yellow and red being frequent in it, but it is also gray, blue and brown in some of its beds. It takes a good polish and is frequently called a marble. In chemical composition it differs from the limestones with which it is associated, containing from 84 to 98 per cent. of carbonate of lime, and 1 to 12 per cent. of carbonate of magnesia. A' a few points in southern Ohio it furnishes the fossil ore for which the formation is famous. In southern Ohio the thickness of the Clinton ranges from 16 to 60 feet.

It is distinctly petroliferous, oil oozing out at numberless points along its line of outcrop, and giving rise to "surface indications" that led, 25 years ago, to the expenditure of considerable amounts of money in futile attempts to secure paying wells at this horizon. Its lower boundary in outcrop is a well marked line of springs.

Under cover at the northward, it has many of the same characteristics. It shows high colors and crystalline structure, but it is more magnesian in composition than in its outcrops. It gives rise to strong sulphur water, and sometimes to highly sulphuretted gas in the Findlay and Bowling Green districts.

Its thickness at the northward seems to be 75 to 100 feet. In the Columbus well, it is a little more than 100 feet thick.

The Clinton limestone is terminated at the southward, and apparently in northern Ohio by a very fine-grained clay. The clay is often white in color, and it generally contains fossils. In the vicinity of Dayton, this seam is prolific in life, and has given a half dozen or more species that are new to science. The clay may be named the Clinton clay or marl. It is rarely more than 2 or three feet in thickness. This Clinton clay seems to be found in its most characteristic form in the wells of northern Ohio, and especially at Findlay and Bowling Green.

4. THE NIAGARA SERIES.

The formation next to be reached in ascending order, is one of the most interesting and important in this part of the column. It occupies about 3,000 square miles of the surface of the State. It is quite a varied and extensive series, numbering 5 distinct and well characterized elements, viz.:

The Hillsboro sandstone.
The Cedarville or Guelph limestone.
The Springfield or Niagara limestone proper.
The Niagara shale.
The Dayton limestone.

The first of these elements to be reached in ascending the scale, is the Dayton limestone. This is a thin, but very valuable member of the group, but is local in its occurrence and need not be described here.

The Niagara shale is a very important member of the series. It has a maximum thickness of 106 feet in Adams county, in outcrop. It grows thinner to the northward. At Yellow Springs, it is about 30 feet thick. In the new oil district the driller sometimes fails to report it, and it may at times be wanting, but in all probability a careful record would show it from 5 to 25 feet thick in every well. It is distinctly

shown at Columbus, being struck in the new well at 622 feet below the surface, and having a thickness of 70 feet.

It is a water horizon in outcrop and under cover. Salt water, rank with sulphur compounds, is produced from it in northern Ohio.

The Springfield stone, or Niagara limestone proper, is a firm, even bedded, fairly pure magnesian limestone, with a thickness in outcrop of about 50 feet. It is blue or drab in color, and is largely quarried as a building stone.

The larger part of the Niagara series belongs to the next division, viz.: the Guelph or Cedarville division, an interesting and valuable formation on many accounts. It is a wonderfully pure dolomitic or magnesian limestone over large areas, furnishing the best limes of this group that are possible. It is a great storehouse of most interesting fossils, almost all of which occur as internal casts. It has a maximum thickness in outcrop of 150 to 200 feet. It occupies all of the surface of northern Ohio that is assigned to the Niagara. It is generally light-colored, drab or cream in tint, but is sometimes blue.

A mass of clean, sharp sand, 30 feet in thickness, that occurs in the Niagara series in southern Ohio, is known as the Hillsboro sandstone, and does not need further description here.

At some points in the State the Niagara is highly bituminous, the asphaltic matter being distributed throughout the substance of the limestone.

5. THE SALINA SHALES.

This is an element of small value at most, in the Ohio scale. There is a question whether any distinct boundaries can be assigned to beds of this age. The last named group may have been formed in part in the Salina epoch.

6. THE WATERLIME OR LOWER HELDERBERG LIMESTONE.

The great sheet of thin and even-bedded light-brown or drab, or sometimes blue magnesian limestones, poor in fossils, but rich in bituminous compounds as petroleum and asphalt, that is found directly overlying the Niagara series, and that constitutes the surface rock for not less than 4,000 square miles of the State, is known in geology by the ill-chosen and misleading designation, the waterlime. Part of the series, no doubt, belongs to the lower Heldeberg, which by some geologists is made distinct from the waterlime, and by some is made to include it. This formation is seen in its best development at Greenfield, Highland county, but at Put-in Bay, at Lima, at Bluffton, at Carey, at Urbana, and at scores of other points, important sections of it are found. It has a maximum thickness of 300 feet, as is shown by the record of the new Columbus well. In sections along its outcrop it ranges from 20 to 100 feet, but the maximum is much nearer the average than the last named figures.

The Niagara limestone and the waterlime together, occupy a large area in northern Ohio, but it is misleading to represent their areas by distinct colors or other symbols on a map. They are sometimes, as at Genoa, both worked in adjoining quarries. The same farm frequently contains several patches of waterlime in a thin cover over the Niagara, and thus throughout the district. More than this, in these drift-covered regions, it is impossible to give a valid judgment as to which rock will be found, in many instances. The separation of them when worked in

quarries is very easily and definitely made. The bedding, the color, the bituminous products and the fossils are distinguishing marks. In composition they are often identical.

7. THE ORISKANY SANDSTONE.

This is an uncertain element in the Ohio scale. A bed or beds of sharp, pure sand, intercalated in the Corniferous limestone, have been designated the Oriskany. There are comparatively few points where this sandstone occurs. Its place in the scale is certainly open to question.

8. THE CORNIFEROUS LIMESTONE.

This is the last of the great series of limestone formations of which the western half of the State is composed. It has two main areas, a belt leading down from Kelly's Island to Pickaway county, and another belt extending across Paulding, Henry and Lucas counties, in northwestern Ohio. A third area occurs in Logan county, underlying the highest land of the State.

In composition, it ranges from 65 per cent. of carbonate of lime to 95 per cent. The carbonate of magnesia ranges from nothing to 35 per cent. It is, on the whole, the purest carbonate of lime that we find on the large scale in the State. It contains many flint nodules, distributed often in regular courses through the rock. The thickest section of it reported in Ohio is 164 feet, at Sylvania, Lucas county. It seems, under cover, to hold about the same measure, but an anomalous section from the Cleveland well may require this measure to be nearly doubled. In its southern outcrops it is not found more than 100 feet thick.

It is generally light-colored, often nearly white. It is even in its bedding and sometimes massive, and yields valuable building stone and lime of high character. Like the waterlime, it carries a small amount of free petroleum, as is shown by the odor of fresh fractures.

The fossils of the formation are exceedingly interesting and abundant.

9. THE HAMILTON SHALE.

This is a formation of rather uncertain character, and quite local in its development. But few feet would be assigned to it in any series. It is generally blue, somewhat calcareous shale, in some places highly fossiliferous, and at other points almost or entirely destitute of fossils. It is probably the Olentangy shale of Winchell.

10. THE OHIO SHALE.

The great shale formation that we next reach in ascending the geological column of Ohio, is of universal importance in connection with the subjects of petroleum and natural gas. It is undoubtedly the ultimate source of the supply of these substances for almost all of eastern Ohio and Pennsylvania, and New York as well. The direct source is found in the sandstones that cover or are imbedded in this shale formation.

This formation consists of black shales and blue or gray shales, interstratified without any definite order. There are patches of black shale, for example, found at one locality, that do not occur in another section. Some of the bands are quite persistent, it is true, but no section can be

furnished that will give even an approximation to the order that will be revealed in a new locality in the central part of the field. The old order that was laid down, of black shales at the top of the column (Cleveland), blue shales in the middle (Erie), and black shales again at the bottom of the series (Huron), is not close enough to the facts as they are now known to be of any service. It is misleading rather than helpful. There are points where just such a section is found, but there is a vastly greater number of localities where no such order prevails. Near the bottom of the shales, black beds, however, always occur. Greenish-blue shales are always found interbedded with darker seams in the middle of the section. On the western outcrop the top and bottom as well are always black. In fact, there is very little but black shale in the section here. Sometimes, however, there is a great uniformity for hundreds of feet.

The thickness of the series depends upon where it is measured. At one point in Highland county, the entire interval between the waterlime and the Berea grit is but 250 feet. Along the western margin or outcrop of the main formation, there are generally 300 feet or more. In the interior, on certain lines, there is a very rapid increase. At Cleveland, the system is about 1,300 feet thick. At Canal Dover, the drill went down through 1,800 feet without exhausting the series.

There are but few sandy seams scattered through this great series in Ohio. It is fairly homogeneous in character aside from the organic matter which it contains. It is in this formation to the eastward that the great oil sands of Pennsylvania and New York are buried, but these are wanting for the most part in Ohio. In the extreme southern border of the State, one or more small beds have been recently found, that perhaps belong at the same general level with the Venango oil sands.

The darkest portions of the series are quite rich in bituminous products as petroleum and gas, and also in organic matter. The latter sometimes rises to 10 per cent. of the rock. It can be expelled by burning the shales, or it can be distilled into kerosene and gas. The petroleum that exists as such in the rock is in comparatively small amount, but its aggregate is large. In some of these black beds, more than one-fifth of one per cent. has recently been found of heavy oil. The bituminous compounds are not, however, confined to the black bands of shale. The lighter bands often contain a notable proportion.

Along the outcrops of the formation from Pennsylvania, through Ohio and Kentucky into Tennessee, gas and oil are constantly escaping. Wells drilled into the shale almost always secure at least a small flow of gas, at least where there are several hundred feet of shale.

11. THE WAVERLY SERIES.

This important group occupies about 7,000 miles of the surface of the State. It is more complex in structure than any of the series that have thus far been passed in review. In it, the first persistent sandstones of the Ohio scale occur. These sandstones are of great account in the accumulation of oil and gas, which ascend into them from the shale formation which they cover. The Waverly series embraee the following elements, which were mainly first distinctly recognized and named by Newberry:

$$\text{Logan series.}\left\{\begin{array}{l}\text{Shale.}\\ \text{Sandstone.}\\ \text{Conglomerate.}\end{array}\right.$$

Cuyahoga shale.
Berea shale.
Berea grit.
Bedford shale.

In eastern Ohio the section is shortest, the entire thickness being sometimes reduced to 300 feet. In central Ohio, a maximum of 800 feet is attained.

The elements are, on the whole, wonderfully persistent and uniform in character. Not even the limestones of our scale can be followed as far with so little change of mineral constitution as the shales and sandstones of the Waverly.

The Bedford shale is an excellent mark by reason of the red color which it very often shows. Where not red shale, it is blue or light-colored, and along its outcrops where it rests upon the dark beds of the Ohio shale, the contrast is well marked. It is 50 to 75 feet in thickness. In northern Ohio, it holds locally some beds of excellent flagging and building stone.

The Berea grit which we next reach, is one of the best known and most valuable strata of the State. In its outcrops, it furnishes our best building stones and grindstones. Under cover, it becomes a reservoir of gas and oil on the large scale.

It ranges from 5 to 100 feet in thickness, but it seldom passes the limit of 50 feet, while it falls below 20 feet for thousands of square miles. The drill is revealing its persistency and continuity to a surprising degree.

Its outcrop constitutes one of the best marked horizons of the State. Being the first persistent sandstone in our scale, and being roofed and underlain alike with shale, it stands out with terrace-like distinctness through much of its western border.

The Berea shale which covers it is a mass of dark, generally black shale, 20 to 40 feet in thickness, rich in petroleum and organic matter, and abounding also in fossils of great interest. Fish remains of unusual character occur in it abundantly in places.

The black Berea shale, making the roof of the Berea grit, helps to mark and determine its place. Taken in conjunction with the underlying Bedford, it forms a series of unique character. A sandstone, the first to be found in ascending, the last to be left in descending the column of the State, this sandstone under cover always a reservoir of salt water, oil and gas, one or all, with a persistent coal-black roof, and underlain with a red or chocolate-colored band for its floor, all this gives to the horizon a picturesque distinctness.

One other surprising element must be added, whether to the Berea grit or to the Berea shale, may be a matter of question. The last named element seems to have the best claim. In the quarries at Berea, at the bottom of the highly fossiliferous Berea shale and thus immediately overlying the quarry stone, a hard, sulphurous layer occurs, black in color but sandy in composition. It is, however, rich in fossils, containing some fish remains of great size and of new types. This last fact, its fossiliferous character, namely, allies it to the Berea shale rather than to the Berea grit. This crust is but a few inches in thickness, and might well be taken, by one who should study it at Berea, only as an altogether local exhibition. But surprising as it may seem, it is co-extensive with the Berea grit. The driller at Macksburg, or in the Ohio valley is as familiar with this hard "cap," as is the quarryman or collector of fossils at Berea.

Immediately below the cap in the oil-producing field, the great supplies of stored gas and oil are found.

The Cuyahoga shale that follows, makes the cover of the oil sand in the large way. It is a light-colored, close-grained, compact shale, quite impervious to water, and thus seals in the contents of the sandstone securely. It is 200 to 500 feet in thickness. It carries frequent layers of sandstone or freestone, some of which are of great value as building stones. The famous City Ledge, of Adams and Scioto counties belongs near the base of the Cuyahoga. The Portsmouth stone and the Waverly brown stone are somewhat higher in the series. The Warren flaggings, of Trumbull county, belong also near the base of the Cuyahoga.

The Logan series is the most anomalous and perplexing of all the divisions of the Waverly, by reason of its inconstancy. It was omitted from the earlier sections, but it proves to be one of the most conspicuous and important parts of the series. The most noticeable element of the Logan group is the Waverly conglomerate, a mass of sandstone and pebble rock, with difficulty, if at all, to be distinguished by physical characters from the coal measure conglomerate. In fact, in all of the earliest reports on Ohio geology, it was unhesitatingly taken for the last named stratum.

It has a maximum thickness of 200 feet, and holds steadily under cover as a great sand rock, generally full of salt water and therefore known in many oil fields as the salt water sand. It sometimes contains high-pressure oil and gas.

It is often overlain by a heavy mass of shales 100 to 200 feet in thickness, which are charged with Waverly fossils. At other points it comes very close to the base of the coal measure rocks and could easily be counted in with them.

12. THE SUBCARBONIFEROUS LIMESTONE.

This is not an important element in Ohio geology so far as its outcrops are concerned. These are few and far between. They occur in Scioto county sparingly, in connection with the flint fire-clay deposits, in Jackson county as the Hamilton township limestone, in Perry county as the Maxville limestone, and in Muskingum county as the Newtonville limestone. But the formation is acquiring new importance under cover. Drillings at many points in the Ohio valley show it to have a thickness of 50 or 60 feet, and by its occurrence it helps to determine the order of the strata that are penetrated.

13. THE CONGLOMERATE COAL MEASURES.

The base of the coal measures is marked by a great accumulation of coarse sand rock and pebble rock at many points. There are three widespread and fairly persistent conglomerate strata, known as the Sharon conglomerate, the Massillon sandstone, and the Homewood sandstone. In the intervals between these heavy ledges, coal seams, coal measure limestones and thin seams of iron ore sometimes lie imbedded. In Ohio, this series of coals has considerable importance, but elsewhere the great sandstones for the most part monopolize the scale and are there known by a single name, viz.: the conglomerate. In Ohio, also, two or more of these strata are often welded together into one mass. The interval between this conglomerate and the Waverly conglomerate is uncertain, except where the last described element, viz.: the subcarboniferous limestone, is interposed, but generally a mass of shales of greater or less thick-

ness occupies the space. Sometimes, however, the two masses are probably found so close together that they are taken by the driller for one.

Shales occur throughout the coal measures in such amount that they furnish suitable cover to most of the great sandstones, making them petroleum reservoirs when other conditions are favorable.

The conglomerate sandstones above named, one or more, frequently become sources of salt water, oil and gas, though no large stocks of the latter substances are derived trom this horizon in Ohio.

14. THE LOWER PRODUCTIVE COAL MEASURES.

The strata of this series have an average thickness of about 500 feet, and include several considerable sandstones. the most prominent of which are the Freeport, lower and upper, and the Kittanning. The Upper Freeport sandstone is thought to become pteroliferous at a few points, as in the Macksburg field, but the determination is not certain.

15. THE LOWER BARREN COAL MEASURES.

In this series, two very important sandstones occur, viz.: the Upper and Lower Mahoning. The Upper is called by the Pennsylvania geologists the Buffalo sandstone. It has a conspicuous place in the Ohio coal measure scale, lying, as it does, between the two main landmarks and guides of the barren measures, viz.: the Cambridge and the Ames limestones. The upper of these sandstones is the source of the shallow oil of Morgan and Athens counties. It is also found productive in Washington county, in the Cow Run field and elsewhere.

16 AND 17. THE UPPER PRODUCTIVE AND BARREN MEASURES.

These groups require no description at this point. They occupy comparatively small areas in souteastern Ohio. They have a combined thickness of about 500 feet, but they are not known to furnish any important stocks of oil or gas.

18. THE GLACIAL DRIFT.

The drift beds of Ohio cover three-fourths of its surface with deposits that rise as high as 445 feet in thickness, in exceptional instances. This extraordinary measure has recently been attained in the drilling for gas at St. Paris, Champaign county. These drift-deposits are uncertain in composition, from point to point, and nothing approximating a general section can be given. The fact that beds of a certain character were found at one locality gives no warrant for expecting a like series at another, a half mile away. These driftbeds are a great source of risk and often of loss to the contractor. He may be obliged to spend weeks or months in getting through 50 or 100 feet of quicksand or bowlder clay. Sometimes a bowlder is struck when 100 or 200 feet of drive pipe are already in the well and the work may then be necessarily abandoned. It is the part of common prudence in sinking a trial well, for both the company and the contractor to locate as near to outcropping rock as possible. The sooner the drill has passed the danger of quicksand and bowlders, the better.

The geological scale of the State has now been briefly reviewed. With the aid of the geological map appended, the distribution and areas

of these several formations (the separate divisions of the coal measures excepted), can be made out. No attempt is made in this map to distinguish the waterlime from the Niagara and Clinton limestones. The latter is found only on the southern margin of the Upper Silurian. In northern Ohio, it is impossible to indicate with any approach to accuracy the relative areas of the waterlime and Niagara limestone, as has been already shown.

SECTION III.—THE GEOLOGICAL STRUCTURE OF OHIO.

A few words are needed at this point upon the *structure* of the State. Under this head is included an account of the dip of the strata, of all axes, arches, folds or anticlinals that occur in its rock formations, and also of all faults or interruptions in continuity of its various elements.

THE CINCINNATI ANTICLINAL.

The dominant feature in the earlier history of Ohio is a low fold, so-called, that entered the State in its southwestern corner, from Kentucky, and that gradually advanced across it to Lake Erie and the Michigan border.

It is called an axis or anticlinal, but there is nothing in it that answers to the common idea of such a structure. It is not a sharp ridge, or in fact any kind of a ridge, but as far as can now be seen, it consists of a flat tract, 30 or more miles in breadth, with very little dip, if any, in an east and west direction, but descending to the northward at the rate of 3 to 5 feet to the mile, with great steadiness and uniformity. When it comes within 20 or 30 miles of Lake Erie, it makes a sharper descent, falling at the rate of 15 or 20 feet to the mile, for that distance. On the eastern side of this tract or axis, the strata begin a uniform descent at the rate of 15 to 25 feet to the mile, in a direction always south of east. The usual direction lies between S. 60 E., and S. 75 E. This rate and this direction hold far within the coal field, giving way to a more southerly direction and being sometimes transformed into a simple southward dip in northeastern Ohio.

The limit of the western slope has not been traced throughout. Probably there is no definite and continuous boundary, but within the area of the original uplift, there are many inequalities in the level of the Trenton Limestone. A line of sharp descent to the westward passes through the town of Findlay, and is connected with the great production of gas at that point. Another such line passes through Putnam and Wood counties, but on the other hand, the surface of the Trenton limestone is approximately at the same level at Van Wert, Lima and Upper Sandusky—or along an east and west line 60 to 70 miles in length. Facts are rapidly accumulating which will give a sufficient basis for generalization upon this point.

There seems no reason to believe, at the present time, that there is within this entire area any facts of structure corresponding to the general idea of an axis, viz.: a tract of narrow breadth, a mile or two at most, extending for many miles or scores of miles, with rapid descents on either side.

It appears that the elevated tract now under consideration received its present structural features at an early day. The Trenton limestone must have been affected by the movements which have disposed it in its present conditions before the great mass of soft rocks by which it is now covered, were deposited upon it. At all events, there is a smaller measure for these shales by 200 feet in the central region, than there is immediately to the eastward. In other words, there is an arch in the underlying Trenton, revealed by the drillers, of which no hint whatever could be obtained by the surface exposures.

It is only on these elevated portions of the Trenton limestone that oil and gas have so far been found. In Findlay (upper level), and in Bowling Green, its upper surface has been found to be 300 to 400 feet below sea level. In the lower level at Findlay, it falls as low as 480 feet below sea level. At Lima it is about 400 feet below. At Carey, where small gas wells have been struck in the Trenton, its surface is 510 feet below sea level. Nothing of real value has thus far been found in it where the top of the Trenton descends below these figures. Of course, good wells may be found at any time, which will overthrow the value of this deduction, but to the present date all the facts brought in have confirmed it.

OTHER ARCHES AND IRREGULARITIES OF STRATA.

In eastern Ohio there are a few low anticlinals that traverse the rocks, affecting them equally from the top to the bottom of the scale. Some of them come in from western Pennsylvania, and gradually die out here. Others originate in Ohio and run their whole course, never a long or marked one, in the State.

East Liverpool and its neighborhood are traversed by one of these folds. Steubenville and the region below it on the river also show similar disturbance. In both cases the disturbance is slight and ineffectual as a means of accumulating gas or oil on the large scale. The fatal salt water dropsy attacks and destroys the wells that are drilled here. There is a slight fold near Salibury, on Yellow Creek. Cambridge is at the center of the most conspicuous uplift in the eastern part of the State. It is quite likely that it extends to the southwestward through Morgan county. There are lines of arrested dip in the vicinity of Gaysport and McConnellsville that may be, one or other, connected with this disturbance. Mineral Point, Tuscarawas county, is a region of disturbed stratification, but no axis has been traced through it.

Sinking Springs, Highland county, and a few square miles around it, contain by far the most striking effects of disturbance shown in Ohio. There are actual faults here of 300 feet or more in amount.

There are also lines of fracture in the shales of northern Ohio that may constitute minor axes. In the valley of the Rocky River, near Berea, good gas wells have been found on these lines of uplift.

There is much more to be learned of northwestern Ohio than has been believed hitherto. A most interesting field of study is opening here, in which fractures and dips, undreamed of in these drift-covered plains, are revealed to us, exceeding in amount and geological importance anything that we know elsewhere in the State. The shore of Lake Erie west of Cleveland, also has many points in this connection deserving of careful investigation and measurement. In the vicinity of Kalida, Putnam county, there is a well-marked structural disturbance. A sharp,

but probably superficial anticlinal cuts the rocks for a considerable distance.

A peculiar form of movement has been experienced at several points in southeastern Ohio, which is found to ally itself with petroleum and gas supply in a most important way. It may be styled the terrace structure. It seems to replace the arch, or rather to constitute the later stages of the arch as it is dying out. There is an arrest of dip in a series that has been found sloping regular in a given direction. For a milê, more or less, the beds run level, or nearly so, and then resume their equable descent. This may be styled the suppressed arch or anticlinal. It was first pointed out by Mr. F. W. Minshall, a sagacious observer and an experienced oil operator, in the Macksburg field. Careful leveling of this field has brought out this structure very clearly. All the oil production of Macksburg comes from the level portion of the rocks or the terrace, a half dozen horizons proving productive within this area, and not outside of it. Gas is found on the upper edge of the oil field where the rocks begin to rise, and salt water is now being reported in the wells on the descending slope of the oil sands.

The determination of all these structural features in Ohio is the more difficult by reason of their apparent insignificance. It is not as in Pennsylvania, where he who runs may read the record of rise and fall, of arch and trough, but here only careful measurements and close observations will detect the departures from normal rates. On the whole, Ohio is a wonderfully regular 40,000 square mile of the earth's crust. In composition and in structure alike, it follows the simplest and the fewest laws that are possible.

PRESENT PRODUCTION OF PETROLEUM AND NATURAL GAS IN OHIO.

Under this head, a few of the leading facts will be given as to the oil and gas fields of the State at the present time.

There are two main horizons of oil and gas now known in the geological column of Ohio, viz.:

The Berea grit.

The Trenton limestone.

There are numerous other horizons at which oil and gas, one or both, are occasionally found, but generally in small quantity. These extra horizons are mainly the conglomerate and coal measure sandstones, but one valuable source of gas remains to be added to them, viz.: the Ohio shale, along its lines of outcrop. These several horizons will be briefly discussed.

SECTION IV.—THE TRENTON LIMESTONE AS A PRODUCT OF PETROLEUM AND HIGH-PRESSURE GAS.

The Trenton Limestone is one of the most widely extended strata of the North American continent. It stretches from the islands north of Hudson's Bay, to Alabama, and from Quebec to Minnesota. It has thousands of outcrops within these wide boundaries. It is known to be

bituminous in New York; in Canada, it yields a little oil; in Kentucky and Tennessee also, it has been credited with oil and gas production, but it was a geological surprise when it was found to be a great storehouse of fossil power underneath the flat country of northern Ohio. It had already been tapped at various points in the State, and had given no sign of such contents. The drill had reached it at Eaton, at Cincinnati in numerous wells, at Columbus, and at a few other points, and in none of them had it given rise to even the suspicion of being heavily charged with oil or gas. The discovery of this new horizon is certainly one of the most remarkable and important discoveries in the geology of the State. The rock is already yielding many million feet of gas per day, of enormous value as a source of power. It is also producing 1,000 to 1,500 bbls. of oil per day, and the development is going forward with great rapidity, and with all of the excitement that everywhere attends such exploitation. At least a half million dollars will have been spent in drilling wells in the new field by the close of the present year, according to present indications. Tankage on the large scale and pipe lines are being introduced into the chief centers of production, and in short, all the familiar experiences in the opening of a new oil-field are going forward here, with a lower Silurian limestone that lies a thousand feet and more below the surface, and the nearest outcrops of which are 500 miles distant, as the base of operations. All this is a complete geological surprise. The practical driller has a maxim to the effect that "geology never filled a tank." Certainly geology takes no credit for the discovery of Trenton limestone oil and gas in northwestern Ohio.

THE FINDLAY FIELD.

The credit of the discovery of high-pressure gas in the Trenton limestone belongs largely to one man, Dr. Charles Oesterlin, an old and highly respected citizen of Findlay. Natural gas has been known in Findlay since the county was first settled. In digging wells, cisterns and sewers, in springs and rock crevices, inflammable gas has been constantly found during the last fifty years. It has been utilized here in the small way for more than forty years. Prof. Winchell, in his report upon the geology of the county in 1872, made mention of the interesting fact that Mr. Jacob Carr had, for a number of years, lighted his house on Main street with gas collected from wells on his premises. The gas was introduced into this house by Daniel Foster in 1838, and has been burning ever since. Other facts bearing on the gas supply were given by Professor Winchell. The composition of the gas had been determined for Mr. Carr by Dr. Chilton, of New York, who pronounced it light carbureted hydrogen and derived from petroleum. The first statement gave the result of an approximate analysis, and the second was a sagacious inference.

The sulphurous compounds of the gas were especially observable. A small percentage of sulphuretted hydrogen goes a good way in advertising its presence. This gas was absorbed by the water of wells and springs, which was made in many cases unfit, or at least unpleasant for use in this way.

Explosions frequently occurred in wells, sewers and other excavations, by reason of the accumulation of the gas. These facts were familiar to everyone, and the presence of the gas was looked upon as an evil to be endured, or as a nuisance that could not easily be abated.

Dr. Oesterlin seems to have been the only one who saw clearly that

there was a source of light and heat in it that could possibly be utilized in a large way. He urged, many years ago, the formation of a company to drill for gas, and when the Geological Survey of the State was organized in 1869, he brought the subject before a member of the corps, but the time had not come for the recognition of this form of power. The experience of Pittsburgh was needed to complete the demonstration that a new source of light and heat is available to at least a few favored districts. The interest in the new fuel that was gradually invading Ohio, made it possible, early in 1884, after several ineffectual attempts, to organize a company to drill for natural gas at Findlay. In this organization, Mr. Charles J. Eckels stood next to Dr. Oesterlin in recognizing and urging the possibilities of Findlay. It is quite certain that drilling would have been undertaken here sooner or later if this organization had not been formed, but in point of fact, it fell to the Findlay Natural Gas Company to make the demonstration by the drill, in November, 1884, that high-pressure gas existed in a firm but porous limestone rock, that was reached at 1,100 feet below the surface of the town. This discovery is the most important, in a practical point of view, that has ever been made in the geology of Ohio.

The drilling was conducted by Brownyar & Martin, of Bradford, Pa., and the immediate supervision of the work was undertaken by Mr. W. M. Martin, the junior member of the firm. To Mr. Martin's intelligent interest in his work from that time to the present, and for the various well-records and important facts that he has furnished, the Geological Survey is under great obligation. The Natural Gas Company in their contract, made the requirement that the well-record should be carefully kept, and that samples should be saved of all changes in the rocks. All this was done, and now Mr. Eckels, already named as a member of the company, took upon himself to collect a full set of samples of drillings, and his work was done with care and completeness.

These drillings of the first well were turned over to the service of the survey, and the record, though unexpected, proved to be surprisingly clear and unambiguous. It was, in fact, the type section of the interval traversed from the New York scale that was here found. The Cincinnati group, of southern Ohio, which has already been shown to be composed of the Hudson River and Utica formations, so blended that the line cannot be safely drawn between them, and that moreover, has in southern Ohio a large and frequently a predominant percentage of limestone, was here found to have lost the latter element mainly, and to be very distinctly differentiated into the typical and representative sections of New York. In other words, there was found here the Hudson River shales of New York, with characteristic color, composition, fossils and thickness, and below them, the Utica shale, in normal section in all respects. The solid limestone underlying the Utica shale had no uncertain place in the column. It could be nothing else but the Trenton limestone.

Further than this, the red shale of the Medina period, one of the distinct and easily recognized landmarks of this portion of the scale, was shown here with a thickness of 50 feet, overlying the Hudson River shale. Above this, were the Clinton shale and limestone, the latter in high colors as in the outcrops to the southward, then the Niagara shale, or at least a few feet of the characteristic fine-grained clay that has been named the Clinton clay, at its very base, and above this, the Niagara Limestone, to the surface upon which or near which, the drill began its descent. All

this was highly satisfactory, and by means of this well-determined section, it became easy to follow the work that was so eagerly taken up on all sides, and when the point of beginning was known, to predict in a general way the section to be found.

This first Findlay section is represented in the diagram that is found on the succeeding page.

The supply of gas obtained from the surface of the Trenton limestone in the first well though vigorous, was not all that was counted possible, and in default of previous experience, it was determined to go deeper in search of a more abundant flow. The drill finally rested at 1648 feet below the surface, still in limestone rock, but no accessions of gas were made in this long and expensive descent. The 552 feet of limestone, unbroken except by occasional slight changes in composition that was passed through in this last descent, probably all belongs to the Trenton age. The Birdseye mark came distinctly to view in the drillings from 1500 feet or thereabouts.

Salt water was struck at a number of horizons, but the most vigorous current came from the bottom. The well was finally plugged 100 or more feet below the gas horizon, and the salt water was mainly held back. A little petroleum came from the gas rock as it was drilled deeper. It was a black, heavy, fetid oil with a gravity of about 35° B.

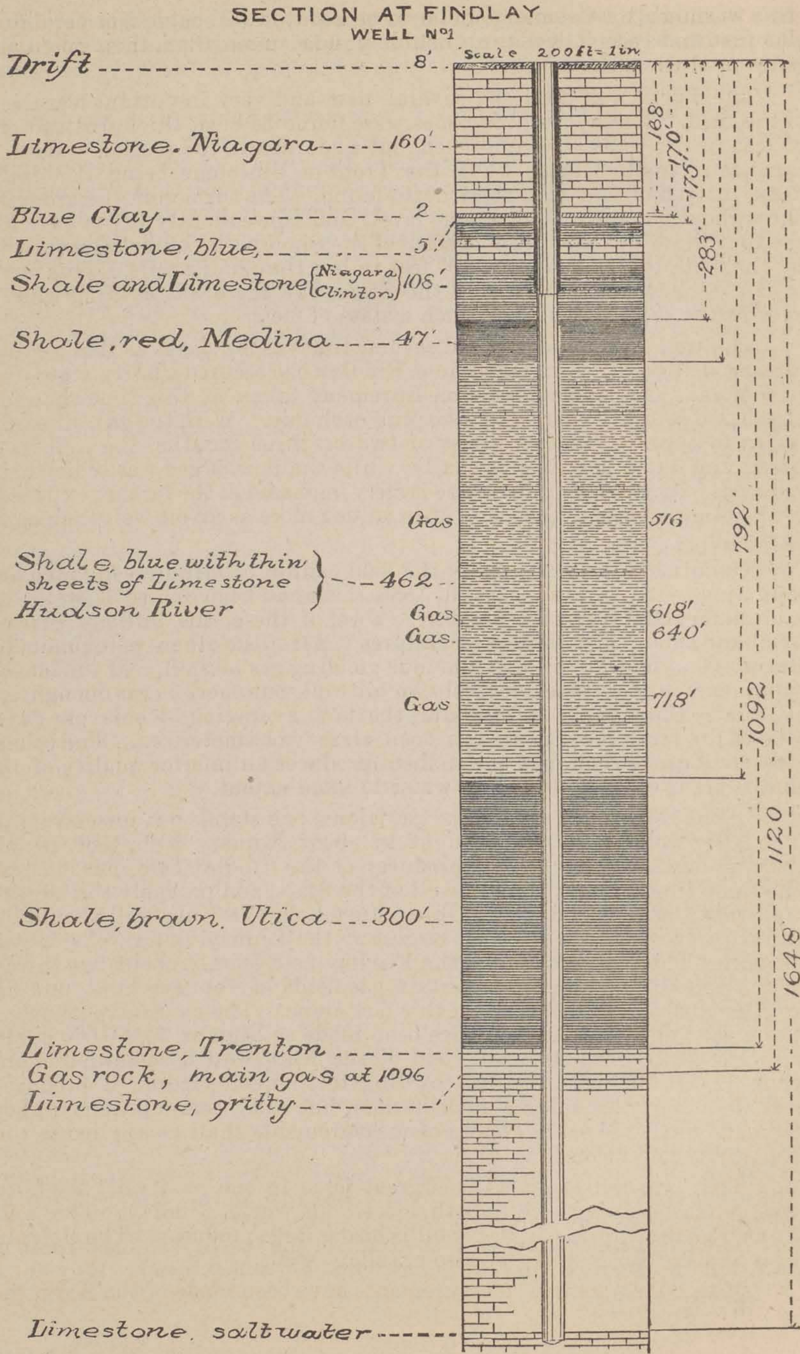
As was to be expected from the surface indications in and about Findlay, gas was found all the way down the well. Notable supplies were obtained at 516, 618, 640 and 718 feet, all in the Hudson River shale, and apparently under limestone caps. The last horizon (700 feet), is a permanent and important one in several wells, and in various parts of the new field. The gas of the Hudson River shales is probably derived from the underlying Utica shale that contains a small percentage of petroleum in addition to a considerable percentage of organic matter. It often occurs in "blowers" or pockets that show high-pressure for a few hours and then disappear altogether. The shale gas generally contains a larger percentage of sulphur compounds than the main supply, but there is a point of view in which this rank odor of both is an advantage. Its presence is at once detected whenever leaks in pipes occur.

The main gas of the first well came with force enough to run an engine when turned into it instead of steam. When lighted from a stand pipe it was visible at night on all sides at a distance of 10 or 15 miles. The flame that shot up from it bore witness to a fact of immense importance to Findlay and to other districts of northwestern Ohio. Curiosity at first bore sway, but this presently was re-enforced by a more practical interest. Other wells were at once projected, and the gas was soon brought into varied use.

The Findlay Gas Light and Coke Company (artificial gas) saw that its occupation was gone unless it too secured the new light and fuel. A well put down by Mr. W. M. Martin for this company early in 1885 repeated the history of the pioneer well in almost every particular. The gas was turned at once into the city mains.

The third and fourth wells were begun about the same time, the one by W. K. Marvin & Sons to supply power for their machine shop, and the other by the Findlay Gas Light Company at the Adams Machine Shop, near the Lake Erie & Western Railroad station.

The third well followed in the track of the two first in most particulars, but the Trenton limestone was found a few feet lower. Its yield of


SECTION AT FINDLAY
WELL No 1
Scale 200 ft = 1 in.
Drift 8'
Limestone. Niagara 160'
Blue Clay 2
Limestone, blue, 5'
Shale and Limestone (Niagara / Clinton) 108'
Shale, red, Medina 47'
Gas 516
Shale, blue with thin sheets of Limestone Hudson River 462
Gas 618'
Gas 640'
Gas 718'
Shale, brown. Utica 300'
Limestone, Trenton
Gas rock, main gas at 1096
Limestone, gritty
Limestone. saltwater
168
170'
175'
283'
792'
1092
1120
1648'

gas was shown by the anemometer to be about 80,000 cubic feet per day. The first and second wells, no doubt, yielded more than this, perhaps twice or three times as much.

The fourth well disclosed several new and very important features of the field. The upper limestones were found 350 feet thick, instead of 250, as in the wells already drilled, but underneath, the section was the same as in the first three wells, the Trenton limestone being 1200 feet deep, instead of 1100 feet, as hitherto found. The surface of the ground throughout the town is all at one level, and consequently it was easy to see that there was an abrupt descent of the whole series of rocks traversed by the drill, to the amount of 100 feet in less than half a mile. This rate of dip is the steepest known in the State, but there was nothing whatever in the surface to suggest such a state of facts.

The well was found to yield several times as much gas as the largest already drilled. For the first time, Findlay had secured a fairly vigorous flow of gas. An anemometer measurement taken at this time showed that 1,296,000 cubic feet were escaping each day. With the gas, oil soon began to appear. In the course of two or three months, the well was producing 4 to 5 barrels of oil daily, while the flow of gas was somewhat reduced. Its yield of oil has since largely increased at the further expense of the other element, until now it is valued more as an oil well than as a gas well.

The further development of the field cannot be minutely followed at this time. By the first of April, 1886, there had been drilled 17 wells in and immediately around Findlay. Two of these, the Putnam Street Well and the Firmin Well, were failures. All of the others were productive, eleven yielding dry gas, and four yielding gas and oil. Of the latter group, one is counted exclusively an oil well, but there is gas enough in it to raise the oil once in 24 hours, the flow averaging 35 bbls. per day. One of the remaining three has been already characterized. The other two yield gas and oil, but one of them produces an inferior quality of oil and is being overrun with salt water to some extent.

Of the eleven wells yielding gas alone, one stands out pre-eminent. The Karg well, which was brought in about January 20th, 1886, is not only by far the most vigorous producer of the Findlay field, but it is, at the same time, the largest gas well of the State, and probably the largest well that was ever known in Ohio. Just how the Karg well should be ranked in comparison with the largest of the Pennsylvania wells, is not certain. The rock pressure of the Findlay field is only about two-thirds of the pressure reported from certain gas fields of Pennsylvania, but no conclusions can be drawn from this fact alone. The *estimated* outflow of the great Pennsylvania wells has been made as high as 30,000,000 cubic feet per day. The *measured* yield of the Karg well is somewhat more than 12,000,000 cubic feet. According to this comparison, it produces less than half the volume of the former, but exact computations cannot be made until the same system of measurements shall be applied to the wells of both sections.

There are two other wells of great force in the field, viz.: the Cory well and the Briggs well, both located in North Findlay. The well known as the North Findlay well is also a large producer. The McManness and the Jones wells are also excellent wells.

Of this series careful measurements have been made of the Karg, the

Cory, the Briggs and the Jones wells, and their respective outflows from or near the top of the casing per day, are as follows:

Karg Well	12,080,000	Cubic Feet.
Cory Well	3,318,000	" "
Briggs Well	2,565,000	" "
Jones Well	1,159,200	" "

These measurements were all executed by Professor S. W. Robinson, of the department of Mechanical Engineering in Ohio State University.

A brief summary of the more important facts in respect to Findlay gas and its production will be here given.

1. The composition of Findlay gas as determined by Professor C. C. Howard, of Starling Medical College, Columbus, is as follows:

Marsh gas (light carburetted hydrogen)	92.61
Olefiant gas	0.30
Hydrogen	2.18
Nitrogen	3.61
Oxygen	0.34
Carbonic acid	0.50
Carbonic oxide	0.26
Sulphuretted hydrogen	0.20

In 100 cubic feet, there are 125.8 grains of sulphur. Its specific gravity is .57. Hence 1 cubic foot weighs 318.98 grains.

The determinations of composition have been repeated a number of times, and at intervals of several months, and all the facts seem to show a steady and constant composition.

2. The heating power of Findlay gas considerably exceeds that of the present Pittsburgh supply, and notably that of the new Grapeville gas, as thus far reported. The best statements in regard to Pittsburgh gas that have been met are those of Mr. S. A. Ford, chemist of the Edgar Thompson Steel Works. They appeared in the Natural Gas Supplement of the American Manufacturer, April, 1886.

He assumes an average chemical composition of this gas, the fact of its instability being well known. From this average composition, he deduces the heating power of the gas, and finds it to be expressed as 789,694 heat units to 100 liters. If a ton of Connellsville coke is counted worth \$2.50, 1,000 cubic feet of Pittsburgh gas is worth $7\frac{8}{100}$ cents, for its heating power.

If a ton of Pittsburgh coal is counted worth \$1.20, 1,000 cubic feet of Pittsburgh gas is worth, for its heat units, $3\frac{1}{4}$ cents. One ton of coal is equal to 36,764 cubic feet of gas.

Professor Howard has applied like calculations to Findlay gas. The results are as follows:

The heat units aggregate to the 100 liters, 878,082.
1,000 cubic feet is worth, coke being \$2.50, 9.4 cents.
1,000 cubic feet is worth, Pittsburgh coal being \$1.20, 3.9 cents.
One ton of coal is equal to 31,085 cubic feet of gas.

The actual prices of coal and coke are much greater in Findlay than those assumed. 1,000 cubic feet of gas may be counted on the basis of actual prices, as equal to 8 cents in coal.

Findlay gas is thus seen to have the advantage at every point.

The heat units of Grapeville gas, according to Mr. John Fulton, aggregate, for 100 liters, 769,766.

Percentages of difference can easily be computed on the basis of the facts here given.

3. The rock pressure of Findlay gas is now about 375 lbs. to the square inch. All wells reach this mark when closed. The large wells reach it in a short time, the Karg well for example, in 1½ minutes; the smaller wells requiring, perhaps, hours. The same line of facts obtains in other gas fields. The futility of estimating the flow of wells from their pressure when closed, is seen from this statement. The large and the small producers meet together on common ground, so far as pressure is concerned. The rock pressure, as nearly as can be learned, has fallen off slightly since the field was opened. In the first wells, 450 lbs. was registered. In none is the limit of 400 lbs. now passed. This fact can occasion no surprise when the immense production of the field in 1886 is considered.

4. The gas and oil production of Findlay are found to be definitely associated with the most marked discordance of structure that is known in the geology of Ohio, except in a single field.

The surface of the town is a part of the great drift plain of this portion of the State, slighлly furrowed by the drainage channels that have been drawn across it. How nearly the surface approaches a plain is seen from the following figures: Of 18 wells that are scattered over 4 to 5 square miles, the elevations of the casings above tide water range between 771 and 788 feet, and 11 of these well-heads are between 779 and 784 feet above tide. The lowest water of the streams is about 10 feet below the lowest well, or 761 feet above tide. There is probably no point within 4 to 6 miles of the town on either side that attains an elevation of 800 feet.

Underneath the surface, this uniformity is lost, and the following facts appear: On the east side of the town, the Trenton limestone is found in a terrace a little more than 300 feet below sea level. In 4 wells drilled here, the extremes of which are nearly one mile apart, the upper surface of the limestone is according to the facts reported, 306, 312, 314, 314 feet below the sea.

To the westward from this terrace, there is a sharp descent to another flat floor of Trenton limestone. To the northward also, there is a descent, but not as marked as the former. The highest westward dip is at the rate of 261 feet to the mile, which stands for a slope of about 3 degrees. It never continues for a mile at this rate, however. It may be added that the limestone floor of the river shows, at a few points in the town, a similar dip, but the exposures are small, and no consideration was heretofore given to them on account of their isolated character. This lower floor of the Trenton is about 475 feet below tide. The main line of strike runs through the town at an angle of N. 14 W.

The wells of the upper terrace all produce dry gas, but in moderate amount. None of them probably exceeds 250,000 cubic feet in a day. As the subterranean slope begins, the wells that are located upon it gather strength and volume. There is but a single apparent exception to this

statement. The great wells have all found the Trenton limestone between 330 and 350 feet below sea level, as is seen in the appended table:

	Trenton Limestone.	
Karg	347	Below Sea Level.
Cory	350	" " "
Briggs	330	" " "
North Findlay	342	" " "
McManness	337	" " "
Jones	328	" " "

When the Trenton limestone is found at 400 feet below the sea, oil and gas are both produced, but the oil tends to increase at the expense of the gas. The following wells illustrate this statement:

	Trenton Limestone.	
Adams Well	405	Below Sea Level.
Barnd Well	403	" " "
Lima Road Well	394	" " "

Where the Trenton limestone is found more than 450 feet below the sea, the well yields either oil or salt water, though gas may still be produced in considerable amount. The following wells illustrate this statement:

	Trenton Limestone.	
Putnam Street Well	452	Below Sea Level.
Matthias Well, No. 1	481	" " "
Matthias Well, No. 2	470	" " "
Firmin Well, No. 1	470	" " "
Taylor Well, No. 1	480	" " "

The Putnam street well was abandoned, but it gave promise of being a small oil-producer. But little gas appeared in it, and it would have been necessary to pump the oil. The Matthias Well, No. 1, has already been referred to. It is the well that flows 35 bbls. of oil per day. The Matthias Well, No. 2 and the Taylor well are both fairly productive.

5. Findlay gas now supplies the town, from the tea-kettle and street-lamp to the mill, the glass-house, the machine shop and the factory. The Natural Gas Company that drilled the Pioneer well, has been absorbed by the Findlay Gas-light and Coke Company, which, under sagacious and energetic management, has obtained a strong hold upon this new-found source of wealth. Fortune has also been propitious in giving to this company the Karg well.

The rates that the company has established are as follows, in part:

For cooking stoves	$1.00	per month.
" sitting room stoves	1.50	" "
" grates	2.00 to 2.50	" "
" house lights	15 to 30	" "
" boilers	from $150 upwards, per y'r.	
" patent lime kilns (draw kilns)	$100 per year.	

Other parties, individuals and companies have drilled wells also, and the work is still going forward. The latest phase is a proposition to bond the town for $40,000, to lay pipes and drill wells if necessary, to supply gas at cost. This proposition has been submitted to a popular vote, and has been carried by an overwhelming majority. If carried into

operation, it would seem to threaten the investments of the corporation that has mainly developed the field thus far.

There has been a deplorable waste of the gas during the last year. This was perhaps a necessary consequence of the conditions under which the development was going forward. In the spring of 1886, there was for months a daily waste of at least 16,000,000 cubic feet of gas. At the rate of value previously determined, viz.: 8 cents to 1,000 cubic feet, this would aggregate a daily loss of $1,280.

These losses should no longer be allowed. The town and the immediate neighborhood give the best of promise of containing a vast supply, but it must not be forgotten that it is stored power. There is, in reality, a measurable amount of oil and gas available, and when this is gone, all is gone. No renewal will follow. Public policy would restrict the number of wells. The more openings the more waste, the more rapid the reducti n of pressure and the sooner will come the inevitable exhaustion of the field. When the great flow of the Karg well was unlocked, other wells, a third of a mile away, were seriously influenced by it. The Adams well lost much of its gas, while the production of oil rose in it from 5 bbls. per day to 15 or 20 bbls. per day. Even the Karg well itself has begun to throw oil in spray occasionally.

6. The inference that all the enterprising towns of northern Ohio were quick to draw when Findlay first "struck gas," viz.: that inasmuch as they were severally underlain by upper Silurian limestone as Findlay is, their chances to obtain the new fuel were as good as Findlay's, is seen to be unfounded. The occurrence of gas and oil in Findlay are associated with an anomalous and most surprising departure from the regularity that in general characterizes the rocks of the State, and the whole question is seen to be a geological one, after all.

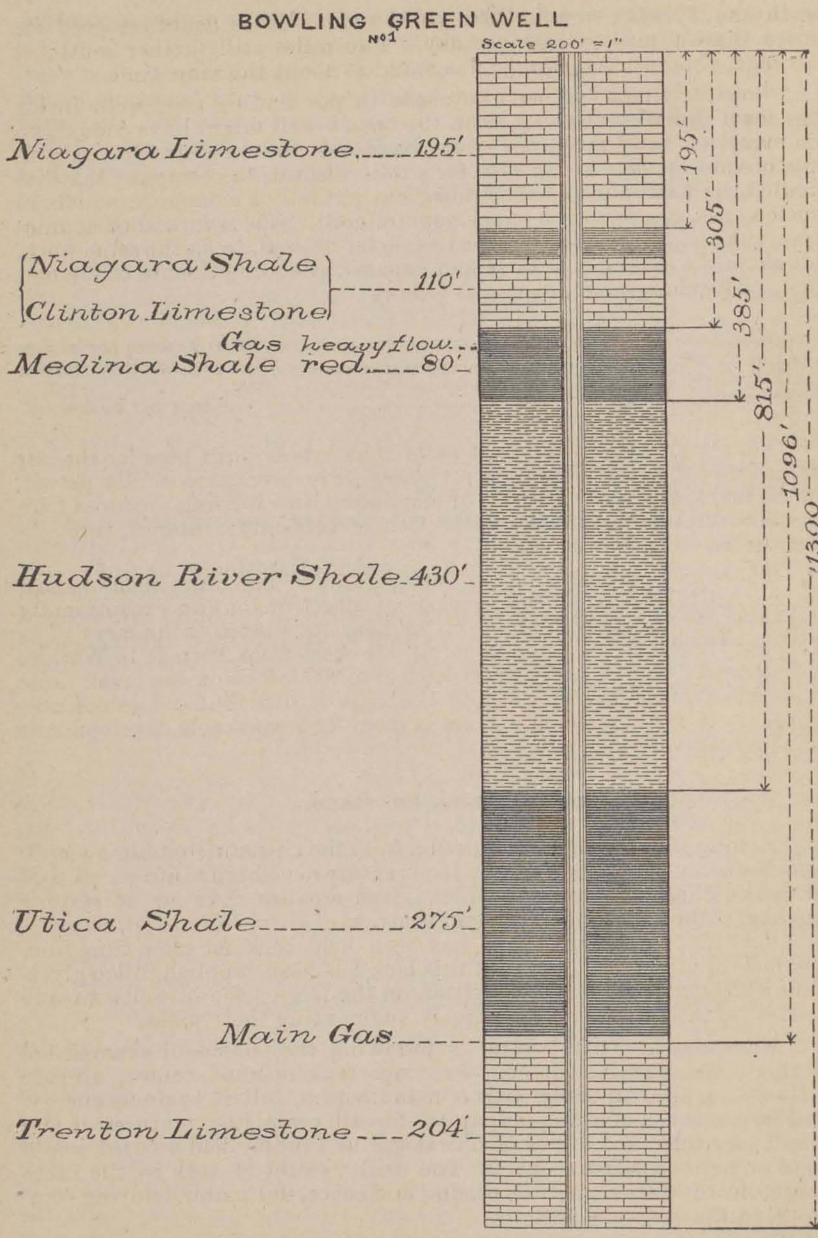
THE BOWLING GREEN FIELD.

Bowling Green, the county seat of Wood county, situated 24 miles due north of Findlay, was the next town to try the fortune of the drill, beginning the work in February, 1885. The Niagara limestone underlies the town as it does a large part of Findlay. The face of the country, however, slopes gently to the northward, and the level of the town is from 80 to 90 feet below that of Findlay.

	Above Tide.
Findlay, Lake Erie & Western Railroad Station	782 feet.
Bowling Green, Toledo & Southern Railroad Station	703 "

The record of the drilling shows an almost exact correspondence with the Findlay records already given. There were 300 feet of upper limestones, interrupted by a thin belt of Niagara shale; there was 80 feet of Medina shale, mainly red in color, about 400 feet of Hudson River shale, about 275 of Utica, and Trenton limestone at 1096 feet, its surface being thus seen to be about 400 feet below sea level. All this is represented in the accompanying diagram. There were vigorous blowers of gas struck as the drill descended, and one in particular, at 330 feet in the Medina shale but probably in a sandy layer, sent out a blaze 30 feet high at first but exhausted itself in about 60 hours.

The Trenton yielded but a very small supply of gas until it was torpedoed. This operation considerably improved its flow. The company



that drilled the first well proceeded to sink other wells and to pipe the town so as to furnish gas for general use, and for the burning of lime, but for a year, their stock of gas was short. In March, 1886, one mile south of the town, the first vigorous well was found. This well is comparable

with the Findlay wells of the third order. It is doubtless good for more than a million feet per day. Two miles still further south, at Portage, another good supply was found at about the same time.

Bowling Green has been fortunate in not finding good wells inside the town limits. Had such been the case, a well might have gone down on every lot, and the supply would have been frittered away. As it is, the productive field being thus far a mile distant, the company that has drilled the wells and piped the town has virtually a monopoly, which, in such a case, clearly tends to the general good. Gas is furnished at rates about one-third less than the cost of wood or coal, to do the same work, let alone the saving of trouble and expense attending the use of the new fuel. The charges are in part as follows:

House lights	20 to 30 cents per month.
Cooking stoves	$3.00 per month in winter.
Heating stoves	3.00 " " " "
Lime burning	one cent per bushel.

Four draw kilns of the best pattern have been built here for the last named use, the preliminary experiences have been successfully passed, in the main, and a good quality of magnesian lime is being produced here at a cost that threatens the extinction of this large interest throughout the rest of northern Ohio.

There has not been drilling enough around Bowling Green to show fully what it owes to unusual geological structure, but an exceptionally heavy dip is known to begin upon or near its western boundary. The Trenton limestone descends in going due west from Portage to Weston, a distance of about 7 miles, from 400 feet to 900 feet below sea level. Just how this average dip of 70 feet to the mile is distributed does not now appear. It would seem that there is room for remarkable developments in this interval.

THE LIMA OIL FIELD.

Among the centers of production from the new horizon, Lima stands scarcely second in importance. It is rapidly developing into an oil field of considerable proportions, which gives promise thus far of staying quality. The daily production on the first of July, 1886, is estimated to be 1100 bbls. This production has been held back for some time from the lack of tankage. Now that this lack has been supplied, nitro-glycerine will be brought into requisition on the large scale in wells already drilled, with the certainty of largely augmenting their yield.

Lima was not long behind in following the successful examples of Findlay and Bowling Green. An important railroad center, already actively engaged in many lines of manufacture, full of business energy, and in command of sufficient capital for all promising ventures, it was easy to see that such a flow of natral gas as Findlay had secured would be of immense advantage here. The drill was set to work by the Lima Straw Board Works, an enterprising and successful manufacturing company, in the spring of 1885.

The trial well was located within the grounds of the company and on the bank of the Ottawa River, the top of the casing being about 850 feet above sea level. The section was found to correspond with the Findlay section in all its essential elements.

There were about 400 feet of the upper limestones, the waterlime re-enforcing the Niagara as it does in the western portion of the Findlay field.

The Medina is not a red shale here, but is greenish-blue, like the underlying Hudson River beds, and it is therefore impossible to draw as sharp lines of division as were found in the preceeding wells. The same line of facts holds as to the Utica and Hudson River beds. The lower part of the Hudson River division is darker in color than it is to the eastward. The lowermost beds of the Utica are dark enough to be called black shale. A little gas was found at various horizons in the shale during the drilling.*

The Trenton limestone was struck at 1247 feet, but to the great disappointment of those concerned, no considerable amount of gas was afforded. But as the drill descended a few feet further, oil was found rising in the well. This was an unwelcome discovery, but to save the venture from being an entire failure, and moreover to test the character of the supply, the well was treated thenceforth as an oil well—that is, it was torpedoed, tubed, packed and pumped. In the first six days, 200 bbls. of oil in connection with some salt water were produced, and the supply then ran low.

The oil was dark, or black oil, heavy and offensive in odor, by reason of the presence of sulphuretted hydrogen. Its gravity after exposure was 36° B. To those acquainted only with oil of the Pennsylvania types, its quality seemed to condemn it.

The Paper Mill well already described was the pioneer well in the Lima field, but by itself it would have made but a feeble impression. It was presently followed by the Citizens' Well, which was put down in the summer of 1885, by an association of public-spirited gentlemen who desired to authenticate the field. This purpose it has served in many ways. It was the first well to yield a steady and regular supply of oil, and it was also the oil of this well that was first tested for refining and other uses in the large way. Forty barrels were sent to Pittsburgh refineries in 1885, and the results obtained did much to inspire confidence in the new production. The well has been an expensive one to maintain. It requires steady pumping night and day to hold the salt water in check. By April 20th, 1886, it had yielded about 5,000 barrels of oil. It must always be counted as one of the most important wells of the Lima field, dividing the honors fairly with well No. 1.

The news that Lima had "struck oil," at once attracted the attention of the wakeful men who control the petroleum interests of the country. For nearly a year previous, in spite of multiplying wells and unremitting activity, petroleum production had steadily fallen below consumption, and the possibility of a new oil field became therefore more than usually interesting and important.

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*A better and more orderly record is furnished by A. C. Reichelderfer, Esq., of the Gas Works Well. It is as follows:

Drift 18 feet.
Limestone.
Sulphur water at 128 feet.
White limestone (Niagara)? begins at 268 ft.
Blue limestone begins at 328 ft.
Limestone with slate streaks continues to 385 ft.

Well cased at 395 ft. No more water.	
Light shale continues to	880 feet.
Brown shale begins at	880 "
Thin black shale at	1228 "
Oil rock struck at	1263 "
Oil-producing "sand"	1255 "
Salt water rock, slushy	1260 "

To most of the Pennsylvania operators that obtained personal knowledge of the Lima well, there seemed but little promise in it. All the conditions were unusual. A flat country, with every outward indication of being extremely regular and undisturbed, at comparatively small elevation above the sea, and the producing rock a lower Silurian limestone, these facts were enough to discourage many who would have eagerly followed up equal promise in a familiar field.

The representative of one Pennsylvania company, however, Mr. I. E. Dean, who was among the first to visit the new field, had been at one time engaged in oil production in Canada, and was well acquainted with its history and value. Mr. Dean was the first to recognize the possibilities here, and to his intelligent and energetic administration most of the early and much of the later development are due. The Trenton Rock Oil Company, organized by him, has done a great deal in the way of proving the new territory. Much of its earlier work proved unproductive, but it had its value in breaking up crude theories and defining safe limits within which to work.

Up to July 1st, 1886, the Lima field has produced 51,000 bbls. of oil. On April 1st, 1886, there were 14 wells in operation, with an average production of 24 bbls. per day, according to local reports, which are never under the mark. On May 1st, there were 22 wells with a much larger average, and at the same time there were 50 or more new wells under contract in the immediate field. On June 21st, the number of producing wells was 34. There were 15 more being drilled, and there were 20 rigs in the field. On July 1st, there were 57 producing wells, yielding 10 to 150 barrels each. Six wells are flowing, and there are 51 new derricks in the field.

All of the earlier wells required to be pumped, but the Shade Well, No. 1, on the south-east side of the town, completed in February, 1886, proved a flowing well. This was the first of six to date. The use of explosives has converted several of the pumping wells into flowing wells, for a time at least.

Some of the wells flow as soon as the rock is struck. The Hume well flowed about 250 bbls. in the first two days. It now yields about 30 bbls. by pumping. Others that have come in dry, as the Clymer well, are converted by a "shot" into productive pumping wells. The last named well yields 10 or 15 bbls. a day. But generally the first behavior of the well is an index to its true character.

As may be inferred from statements already made, the geology of the Lima field is substantially one with that of Findlay. The whole region is underlain with the waterlime, the rock being exposed and quarried in the deeper valleys in and around the town.

The elevation of Lima is about 100 feet greater than that of Findlay. Unfortunately, the elevations given by the several railroad surveys do not agree.

The elevation of the track at the Dayton & Michigan depot, as given by this road, is 859 feet above tide. A probable correction of 15 feet will bring this figure to 874 feet. By the Lake Erie & Western railroad, the elevation of the same point is given as 885 feet, and by the Pittsburgh, Fort Wayne & Chicago railroad, as 873.5 feet. The track of the Chicago & Atlantic road on the south side of the town at the station, is given as 903 feet, but this measurement is entirely independent of the others. These discordant figures have not been harmonized, but inas-

much as the Lake Erie & Western elevations have been used in the Findlay field, the figures of this road will be used here also, although it is probable that they are about 11 feet in excess.

Almost all of the town and of the county adjoining it for several miles on either side, will be embraced within the range of 850 to 900 feet above tide (L. E. & W. crossing, 885).

The oil wells range from 1,240 to 1,290 feet in depth. The surface of the Trenton in 14 of the first 20 wells drilled, the extremes of which are 12 miles apart, ranges as follows:

390	Feet below tide.
390	" " "
393	" " "
394	" " "
395	" " "
395	" " "
396	" " "
400	" " "
403	" " "
406	" " "
407	" " "
421	" " "
432	" " "
445	" " "

The first ten of the list are located in Lima, or immediately adjoining it.

The records that the wells have made with reference to oil production are significant in this connection.

The first two wells flowed oil when the rock was struck (Trenton, 390 below tide).

In the third case, the oil flowed after the well was torpedoed. (Trenton limestone, 393).

The four wells next on the list are all pumping wells, and yield an average of about 20 bbls. Several of them have been torpedoed with good results as to production, but without converting them into flowing wells. —(Trenton limestone, 395–396).

The remaining wells (Trenton limestone 400 feet and more below tide), are all practically failures. It is claimed that the well in which the Trenton is 406 feet below tide would, if pumped, prove a 10-bbl. well, but neither this nor any of the others is pumped at the present time. The last three are plugged and abandoned.

It is surprising to see on what a narrow margin success in drilling has thus far turned. It is scarcely possible that this margin will be maintained throughout the field, and the results of later drilling will prove very interesting when brought into comparison with these earliest figures, but thus far certainly geological structure is seen to be connected in a most important way with the yield of oil from Lima wells, and especially with the differentiation of these wells into the several groups already named.

The salt water in any case lies very near the oil. In many wells both are constantly produced. If the pumping is stopped the salt water overcomes the oil. A cessation for a single Sunday in the Citizens' well reduced the daily production of oil from 11 to 8½ inches in the tank, and

it required steady work for an entire week to restore the flow. In such cases it would seem that a short stoppage would prove fatal. The brine is of the peculiar character already noted in the other fields, being more of a bittern than a brine. It is produced from the wells perfectly clear, and with a temperature of 80° F. In many of the wells it is counted no special disadvantage, but is pumped steadily with the oil. It cannot be separated under ground, whether disadvantageous to the well or not.

Character of the Lima Oil.

The Lima oil is a *limestone* oil, which is as much as to say that it is a dark, or black, sulphuretted, and rather heavy oil. In these respects it agrees with Canada and Tennessee oils. There is quite a range in gravity, however. In the first well, the oil had a gravity of 36° B., but in most of the later wells it reaches 37° or 38,° and in the McCullough well it reaches the high mark of 41° B. Several tests have been made on a fairly large scale, and the results show that the oil can be completely deodorized, that it carries 65 per cent. of illuminating oil, and 26 per cent. of lubricating oil of excellent quality, and other merchantable products.

These results were obtained in Canada refineries where several barrels were sent, and they are, on the whole, the most favorable that have been reported. The oil was thoroughly deodorized, and each of the several products showed high or fair quality.

From a test made in Philadelphia, a somewhat better percentage of illuminating oil was reported than that given above, but the products were unmarketable by reason of their offensive odor.

The Downer company of Boston, also makes a favorable report.

The latter company has united with the Edwards Oil Burner Company, of Chicago, to establish a refinery in Lima, and here, without doubt, the best results will be speedily obtained. The work of construction is already going forward, and refining operations will be undertaken at an early day, in which the best appliances and the highest skill will be employed. The refinery will have on completion, a capacity of 250 bbls. per day.

The promise of the field depends largely on the success of this undertaking. At present, the price of Lima oil is 40 cents per barrel, and there are many wells that cannot be pumped for what they yield, but if the value of the oil could be increased 50 or more per cent. their production could still be maintained. The increase of price is to be looked for from the success of refining operations at home.

Tankage and Transportation.

Indispensable to a modern oil field are the great systems of storage and transportation that American practice has evolved. The Lima field is soon to be supplied with large tanks and with pipe lines. In fact, the work in both is already well under way.

The Buckeye Pipe Line Company, which is an organization under the same management as the National Transit Company, has nearly completed one 36,000-bbl. tank, and has two others of the same size already ordered. The usual system of piping the wells will be at once introduced, and thus the transfer of oil will be accomplished with as great dispatch and as little expense as possible.

Extent of the Field.

The Lima oil field proper extends from the central portions of the town eastward and southward. Comparatively little drilling has been done to the westward or northward, or north-eastward, the earliest ventures being such as to discourage furthor exploration in these directions. A good well has been obtained 3 miles to the south-east of town, and the interval is now being quite thoroughly tested. The field may be held to extend as far as a fairly continuous series of wells can be followed. Its eastern boundary is not yet defined, but enough wells are now in progress to furnish important testimony in regard to it when their records are complete. Even the districts in which failures have thus far occurred are not to be considered as beyond hope, but patches of productive territory are likely enough to be found within them, under the thorough search that is now going forward. It would be unprofitable to attempt to lay down the metes and bounds of a field in such an active stage of development as Lima is now passing through.

THE BLOOMDALE GAS WELL.

A very important extension of the Findlay gas field has lately been made by the sinking of a successful well at Bloomdale, a village of Wood county, on the Baltimore & Ohio railroad, 7 miles west of Fostoria, and 10 miles north-east of Findlay. This well was drilled in May, 1886. The casing stands at 755 feet above the sea, and the Trenton was reached at a depth of 1115 feet. Its upper surface is thus seen to be 360 feet below sea level. It is at about this level that all the greatest gas wells at Findlay have been found (Karg, 347, Cory, 350, Briggs, 330, &c.)

The Bloomdale well proves to be one of the strong wells of the district. Its outflow was measured on June 16th, but the results obtained were somewhat discordant. Enough was learned of it, however, to warrant the statement that it probably stands next to the Cory well of Findlay in production, the Karg well, of course, being excluded from the comparison. Its daily yield at present, does not vary much from 3,000,000 cubic feet.

The discovery of this vigorous supply at a distance of only 7 miles from Fostoria, an ambitious and enterprising town that has thus far vainly sought for gas within its own boundaries, two wells having been drilled to the Trenton limestone, is one of the important facts of the later developments of the field. The new territory will be fully tested forthwith, and Fostoria will at once proceed to pipe the gas as far as it is necessary, test wells being drilled in the interval between the two towns.

Such a supply is of much greater value to a community than one that is found within the town boundaries, and thus easily accessible to all landowners. There is better promise of its having a full term of life, and the capital invested in its development may, under such conditions, secure a due reward. Manufacturing enterprises can more safely be established on such a supply.

Bloomdale, of course, may repeat to a limited extent, the experience of Findlay, and sink a number of unnecessary wells, but it is to be earnestly hoped that this ruinous policy will be avoided, and that gas will be drilled for here only when it is needed, and when proper provision has been made for its use.

The results of new explorations in this field will be watched with great interest.

THE TRENTON LIMESTONE IN OTHER FIELDS.

As already stated, Bowling Green and Lima were the first two towns to follow the example of Findlay in drilling to the Trenton limestone, and both were successful in their search. It was a strange fortune which made the first three efforts so nearly exhaust the successes in this entire field, up to the present time. With this early record in hand, it seemed to all north-western Ohio, that in regard to natural gas and oil, it was but to ask and to receive. For a few hundred dollars the drill could be sent to what was believed to be a universal and perennial supply of light and heat and power.

Of the twenty-seven counties that occupy in a solid block north-western Ohio, extending from Dayton and Springfield northward, and from Sandusky, Bucyrus and Marion, westward, every one has sunk, or is now sinking a well to the new-found region, viz.: Trenton limestone. In a number of these counties more than one well has been drilled, and in some, a half dozen, but it still remains true that with a single exception, and that a not very important one, the three counties of Hancock, Wood and Allen, contain all the really valuable supplies that have been so far found.

THE CAREY GAS WELLS.

Of the towns that have attained a measure of success outside of those already named, Carey, Wyandot county, deserves mention.

Two wells have been drilled here, the first of which found a small, but thus far persistent flow of gas from the Trenton limestone. The depth at which the Trenton was struck is 1326 feet. The elevation of the well-head above the sea is about 813 feet, and consequently the upper surface of the Trenton is a little more than 500 feet below tide. This is the lowest point in the rock in which gas in any notable volume has been found. The closed pressure of the well is reported at 335 lbs. but no measurement has as yet been applied to its outflow.

A second well that was drilled here is reported as smaller in production than the first. Other wells are likely to be drilled at this point, but thus far there is no indication of high-pressure gas in this field. The supply, if it is maintained, is, however, well adapted to domestic use and to the production of steam for ordinary purposes.

THE FREMONT GAS WELLS.

Fremont, the prosperous county seat of Sandusky county, has taken a lively interest in the new-found fuel of northern Ohio, from the date of its discovery in Findlay. The first well was drilled here in the summer of 1885. The Trenton limestone was found about 700 feet below sea level.

Gas was found in small amount in the shales that were traversed by the drill, and especially in the Medina horizon. The Trenton limestone did not make, in fact, very notable additions to the supply obtained before it was reached. The whole amount of gas flowing from the well a month after it was completed was less than 10,000 cubic feet per day.

A second well that was sunk soon afterwards was more successful, but it was also apparent here that the gas came in large part from the Medina or Hudson River shales. In the wells next drilled, the upper sources only were reached, the wells not being sunk deeper than 600 feet. These shallow wells are the best of the field thus far, but they are small producers. The second in force gives by meter, 17,000 cubic feet per day.

The gas is excellently adapted to domestic use, but the wells lack the force and vigor necessary for a manufacturing supply.

Eight wells have been drilled up to the present time, and more are under contract.

There are nearly or quite fifty other towns of the western half of Ohio that have been inspired by the success of Findlay and Lima, to drill to the Trenton limestone within the last eighteen months. Most of these towns have already completed one well, and several of them have undertaken a second or even a third. In a number of instances, the drill has been carried down for hundreds of feet into the Trenton limestone, but without advantage in any case. Nothing has been gained from below the uppermost fifty feet of the limestone.

Some of these wells are absolutely "dry," and are acknowledged to be unsuccessful ventures. Even to nitro-glycerine they make no favorable response. In a much larger number oil and gas have been found in small quantities. Of the latter class, some wells will yield a few hundred or a few thousand feet of gas per day, or from them a few barrels of oil have been or can be obtained. Wells of this character are often counted by the companies that have drilled them as very different from "dry holes." They are thought to give fair promise to the fields in which they occur and to justify further exploration. The first well in Lima made but a poor production of oil, and much account is made of this fact. There are many towns in Ohio that count their first wells as promising as the first Lima well, and they draw from this comparison much encouragement, much more, indeed, than the facts when fairly understood will justify.

The history of a score or more of these wells is substantially as follows:

When the drill has been sunk 10 to 40 feet into the Trenton limestone, oil is found, generally, in small quantity, but sometimes it rises in the well for several hundred feet. Of course, a little gas accompanies

it. To secure a large flow, the drill is kept at work and presently salt water is struck. Sometimes, in fact, the oil and salt water are reached at exactly the same point. The salt water also rises in the well, carrying the oil above it, and occasionally causing overflows. The entire column is generally credited to the oil account. The baler is set to work, and a half dozen barrels, more or less, of oil are obtained. At this point, the well is either tubed and packed, or it is "shot" and made ready for pumping. Generally the latter course is taken, and 30 or 40 quarts of nitro-glycerine are exploded in it, at the level of the oil-producing rock, after which the tubing is introduced. A tank is frequently constructed and the pump is set to work. For a few hours, the promise is fairly good, and 5, 10, or even 20 or 30 barrels of oil are delivered. At this point, salt water begins to appear, or production of all sorts may be arrested. The decline is generally attributed to sand in the valves. The pump is drawn but nothing is found wrong. After an interval, a little more water and less oil are pumped, or perhaps a steady flow of brine appears, but presently it is found that no more petroleum is available in this particular well. But it is often held that the well has been successful in demonstrating the presence of oil and gas in the field, and that now it only remains to find the particular localities where they occur in "paying quantities." The first well, it is believed, was carried a foot or two too deep, but when a second well is drilled no amount of care prevents a repetition of the experience of the first.

It would be a pleasure to record the success of any field whose history opens in this way, but thus far no opportunity has been given. Oil and gas in "paying quantities" still remain to be discovered in such districts.

Wells of this character are much worse for the towns that find them than dry holes, because encouragement is often derived from such facts for a second and a third venture. which have thus far, in every case, resulted in the same way as the first. The first Lima well is not a case in point. It was not handled properly for an oil well, being the first in the field. Practical men saw from the record that its promise was fair.

The further tests that have been undertaken will doubtless supply during the present year materials for a more decisive judgment in the case of many of these districts, and nothing need be said to cloud their titles at the present time, except as they may be involved in certain general conclusions that are now to be stated.

CONCLUSIONS AS TO THE NEW FIELDS.

1. From the facts already stated, it is obvious that the discovery of oil and gas in the Trenton limestone of northern Ohio is invested with great economic interest and importance in the localities that have been specially named. Fuel of such character as Findlay gas, has become in our day a factor of the greatest value in many lines of manufacture, and the towns that can secure it gain such an advantage that competition with them is difficult or impossible on the part of towns that are without it.

Oil is in like manner power. In addition to all other uses, it furnishes the best of fuel. Excellent facilities for using it as fuel have been provided of late, and some of these are already introduced on the large scale into Lima and adjacent towns.

The eager search for the new fuel, whether gas or oil, that has been going on and that is still continued in the State, is fully explained, and in a measure justified by the extraordinary value of these substances when found at their best.

2. The supply of valuable accumulations of oil and gas from the new horizon has thus far been found to be very sharply limited. There are four productive centers at the present time. Others will doubtless be added, but probably within or near to the general boundaries already pointed out. The inference that was hastily drawn from the experience of the towns that led in the search, viz.: that all of northern Ohio is good oil and gas territory, has been proved to be unfounded. The oil of Pennsylvania and New York has all been derived thus far from less than 400 square miles of working territory, but these 400 square miles are distributed through many thousands, and even through tens of thousands of square miles. The production of the Trenton limestone in Ohio may prove to be as sparsely and as apparently capriciously distributed throughout the districts which it is known to underlie as is the production of the great sandstone sheets of Pennsylvania.

3. The productive territory lies in *spots*, and the different centers cannot be connected by any lines or belts that it is at all worth while to draw. Any two places can be joined on the map by a straight line, it is true, but not a line can be drawn between the productive districts at present known, which is not broken by failures where drilling has been attempted, and no line has yet been found that would lead the driller to fortune. The north-east and south-west line derived from Pennsylvania experience, is perhaps, the favorite direction in the new field also. Lima lies to the south-west of Findlay: so far, good, but in the same line lies Fostoria with two dry holes, Fremont, without a single well in the Trenton that deserves mention, out of a total of eight wells. Between Lima and Findlay, wells have been drilled at four points, viz.: Beaver Dam, Bluffton, Mt. Cory and Rawson, and all are failures. To the south-west of Lima is Celina, where the Trenton is reported unproductive. Out of a total of nine locations on this line, two are productive.

Another line on which great expectations have been built, is the north and south line connecting Findlay and Bowling Green, but the line is broken in the middle and at both ends. Between Bowling Green and Findlay, the New Baltimore well has showed unproductive ground, at least in the first well. North of Bowling Green are the three unproductive wells of Toledo. South of Findlay, Arlington, Kenton, Belle Center, Urbana and Springfield have made an unavailing search for oil or gas in the Trenton. In this case, two localities out of nine in the line have proved successful. Such lines or belts, it is obvious, are worse than none.

The Canada oil field is frequently included in the same belt with Lima and Findlay, but the Canada oil is derived from a rock that is not present at either of these last named points. Its place in the Findlay scale woul be 300–400 feet in the air. The Corniferous limestone is the Canada oil-rock, and the Trenton is never approached within a thousand feet in this field, and moreover, there is good reason to believe that the Trenton arch in Ohio was formed ages before the Canada oil rock was deposited.

4. The most important line of facts that has been brought out thus far by the study of the field is the connection which is found to be main-

tained between the productive areas of the Trenton Limestone, and the level which its surface holds with reference to the sea. All of the present production is derived from a quite narrow range of elevations. The gas wells of Findlay find their supply where the limestone lies between 306 and 350 feet below sea level. The *great* gas wells of the field are thus far included in the interval between 330 and 360 feet, both included, below sea level. The gas wells of Bowling Green, including Portage, all find the Trenton at 380 to 400 feet below the sea.

The oil of the several fields has scarcely a wider range. The deepest steady supply of oil comes from the Matthias well, at the foot of the Findlay slope, where the Trenton limestone lies 481 feet below the sea. The bulk of Findlay oil, however, comes from between 400 and 460 feet below the sea. Lima oil is derived from the Trenton, where its surface ranges between 390 and 400 feet below the sea. It is highly probable that wider limits will be established under the active development that is going forward, but up to the date when the facts were taken, all the wells agreed fully with the statements here given.

In the Lima district, the descent of the surface of the Trenton to 400 feet or more below sea level, is instantly fatal to it as a source of petroleum.

In no case has oil thus far been produced in any persistent supply from the Trenton limestone where its surface is 500 *feet below the sea.* The deduction is obvious. Where the surface of the limestone is found 500 feet or more below the sea, one well is enough to determine the character of the immediate field, according to present knowledge. The Carey wells mark the limit in this direction. The Trenton limestone here lies 513 feet below sea level.

The provisional character of this conclusion is fully recognized. It will lose its validity when set aside by a new fact, but so long as it is maintained it can be made useful in limiting exploration as already suggested. Large districts are promptly condemned by this deduction. It may be charged that this is a prophesy after the fact, that only by the failure of the well can the law be extended. It is true that a certain amount of exploration must precede a valid conclusion, but the latter is by no means limited to the particular districts in which the exploration is carried on. Take for example, the drilling that has gone forward in towns on the Dayton & Michigan railroad, north of Lima. In the well drilled at Columbus Grove, the Trenton was struck at 526 feet below sea level; in the Ottawa wells, at 639 feet; in the Leipsic well, at 701 feet, and in the Weston well, at 905 feet. At Toledo, also, its surface was found 800 feet or more below the sea. Not only is further drilling in these localities discouraged by this conclusion so long as it stands unimpeached, but the geological structure of the counties to the west of this line is such as to make it certain that their condition is worse in this respect than that of the towns that have already experienced failures. That is, the Trenton limestone lies lower in them than in the regions already found barren. In Van Wert county, however, west of Lima, the Trenton is found at a level more favorable, so far as this deduction is concerned. Its surface in the Van Wert well is 434 feet below the sea, and in the Delphos well, 447 feet below. Further exploration may well enough be undertaken in this region.

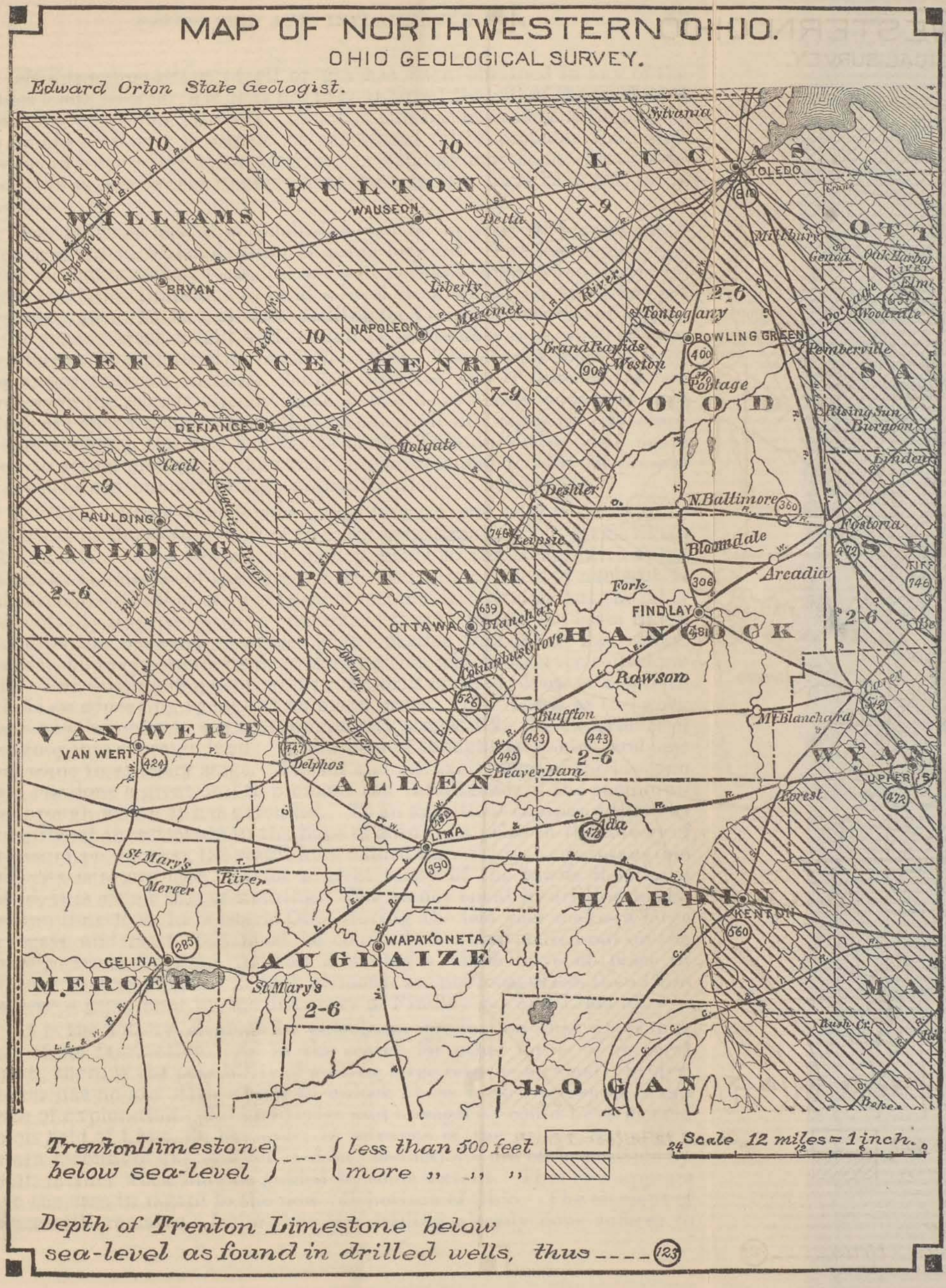
By the application of the same deduction, the eastern boundary of the field lies along the line of the Columbus, Hocking Valley & Toledo railroad. Wells have been drilled on this line at Marion, Upper San-

dusky, Carey, Fostoria, Bradner and Toledo. The record of the Marion well is not satisfactory. According to the current figures, the Trenton limestone here lies at about 700 feet below the sea; at Upper Sandusky, it is 470 feet below; at Carey, where it produces a moderate amount of gas, it lies 513 feet below; at Fostoria, where two dry holes have been drilled, it is 472 feet below; at Bradner, 529 feet below, and at Toledo, as previously stated, about 800 feet below sea level.

The line of elevations here given belongs, of course, to the counties already named. There is no known significance as yet, outside of these districts, in the fact that the Trenton limestone lies 300 or 400 feet below the level of the sea, so far as oil or gas production is concerned. The limestone, as already shown, rises slowly to the southward. Its upper surface reaches sea level not far from the parallel of Dayton. At Cincinnati, it is about 200 feet *above* sea level, though still buried several hundred feet deep, and in the valley of the Kentucky River, it rises to-day, having here an elevation of 500 to 600 feet above the sea. Through the northern portion of Darke county, through Shelby county and probably through Logan, there is an arrest of the northward dip and a small reverse dip is established. The Trenton lies 40 feet higher at Union City, Ind., than at Greenville, and 40 feet higher at Sidney, than at Piqua. This interruption might well be expected to connect itself with oil or gas accumulation, but so far the limestone in this belt has proved entirely barren.

The deduction as to the connection between its petroliferous character and its absolute level is not, therefore, to be applied much beyond the south line of Allen county, according to present experience. It seems almost certain, however, from the latest developments, that portions of Auglaize and Hardin counties will yet be found to hold valuable stocks of oil or gas. They are very closely connected with producing territory. But the result of a considerable amount of drilling done to the south of this line is certainly discouraging. At no point has the limestone been found charged with oil or gas in sufficient quantity to pay for the present or to warrant further exploration. More than 25 wells, distributed through 13 counties, have been sunk to the Trenton limestone within this district, but the rock has not yielded to a single one of them any adequate return in the way of light or heat. At Cincinnati, these wells do indeed furnish power, but it is water power. They have proved artesian wells, and the strong flow which they send out from the deeper courses of the Trenton is utilized in elevators. New wells are being drilled for the express purpose of securing this form of power. The deep water of these wells is quite highly mineralized, and is popularly identified with the Blue Lick water of Kentucky. Some value is attached to it as a medicinal water, at several points where it has been reached.

In the accompanying map of a number of counties of north-western Ohio, the areas in which the Trenton limestone is found more than 500 feet below sea level, are indicated by shading. The north-western and the north-eastern boundaries are established on a larger number of facts than the remainder. In Hardin county, particularly, and also in Logan, the lines laid down have but little to rest on, and not much reliance is to be placed in them. Much of the boundary is provisional only, and when more facts are in hand the included areas will possibly be represented by an archipelago instead of by a single mass. One outlier of Trenton less than 500 feet below sea level is to be noted at Upper Sandusky. The surface of the rock here is reported at 472 feet below the sea.


MAP OF NORTHWESTERN OHIO.
OHIO GEOLOGICAL SURVEY.
Edward Orton State Geologist.
WILLIAMS
FULTON
LUCAS
DEFIANCE
HENRY
WOOD
PAULDING
PUTNAM
HANCOCK
VAN WERT
ALLEN
HARDIN
MERCER
AUGLAIZE
LOGAN
TOLEDO
Sylvania
WAUSEON
Delta
BRYAN
Liberty
Maumee
NAPOLEON
Grand Rapids
Weston
Tontogany
BOWLING GREEN
Portage
Millbury
Genoa
Pemberville
Woodville
Rising Sun
Burgoon
DEFIANCE
Cecil
Holgate
Deshler
N.Baltimore
Fostoria
PAULDING
Leipsic
Bloomdale
Arcadia
FINDLAY
OTTAWA
Blanchard
Columbus Grove
Rawson
Bluffton
Mt.Blanchard
Carey
VAN WERT
Delphos
Beaver Dam
Forest
UPPER S
LIMA
Ada
St.Mary's River
Mercer
KENTON
WAPAKONETA
CELINA
St.Mary's
Rush Cr.
10
7-9
2-6
810
400
370
908
360
472
746
306
481
639
526
447
424
463
443
445
478
390
285
560
512
Trenton Limestone below sea-level
less than 500 feet
more " " "
Scale 12 miles = 1 inch.
Depth of Trenton Limestone below sea-level as found in drilled wells, thus ---- 123

No large production of oil or gas has been obtained in any of the shaded areas thus far, but it is not to be inferred that all of the unshaded portion is promising territory. Much of this has been already found barren by the drill. It is also to be considered fairly probable that accidents of structure like those described in Findlay may somewhere determine production in the regions that thus far we have been obliged to condemn.

It is believed that this conclusion can be applied with great profit to the regions in which drilling is going forward. The towns may still insist on making their tests, but one will perhaps suffice when the record shows the lower limestone to be at a level from which no value has yet been obtained. In fact, all new drilling for Trenton limestone oil or gas, in the shaded areas, might well enough be left in abeyance, until at least one success is registered in such territory. There are a score of wells now under contract in these clouded districts, and if their records all agree with the records already made, it will be as nearly certain as most things are that we call certain, that no new well will repay its projectors. A line showing the 400 feet levels of the Trenton would come much closer to actual production than that here represented; but for the present we must be content with rough approximations to boundaries.

5. The drilling that is now going forward and that is likely to be continued in the western half of Ohio for some time to come, seems likely to bring little or no reward in money value to the communities that undertake it, outside of the three or four counties previously named. It makes a redistribution of a good deal of accumulated wealth, but the labor is essentially unproductive in character—that is, it does not seem likely to add to the material resources of the parties that make the outlay. There is, however, another side to the question which deserves consideration. The drilling of a deep well in the drift-covered plains of northern Ohio is an educating agency of no mean order. The record, as the work progresses, becomes to a whole community, almost like the experience of a journey into a foreign land. A new field of thought is opened, and new ideas come in at every stage. The oil and gas excitement of the last two years has done a great deal to promote the intelligence of the communities through which it has extended. To an ambitious company that has made liberal investments in the hope of gaining a prize in the lottery of petroleum production, the result here named may seem a very intangible and unsatisfactory one, but for a great many of the towns that have drilled, it is either this or nothing. The money spent in drilling to the Trenton limestone in western Ohio during the last year makes a large aggregate, and most of it must be counted as water poured out on the ground, except for these indirect advantages which have no place in ordinary balance sheets. If such elements are not recognized, then Ohio has been a great loser by the discovery of Findlay gas and Lima oil.

It is the lottery element in petroleum production that gives to it most of its fascination. As in the search for other forms of mineral wealth, there is the possibility of getting large returns for small outlays. Science has no key with which to unlock these buried treasures in advance of exploration. No knowledge and no sagacity could have located the oil field of Lima, for example, in advance of the driller, but after a certain amount of exploration is done, deductions are often possible by which further work may be guided to some extent. This now appears to be the case in regard to the new oil horizon of Ohio. The element of chance still remains a factor, but the drilling already done suffices to

show that outside of certain narrow boundaries the dice are at least loaded. Each new failure gives new validity to the interdict against drilling that the results of one year's explorations have applied to large sections of western Ohio.

The facts here presented when candidly considered will discourage much of the promiscuous drilling that is now going forward. Especially will they discourage the drilling of second and third wells in many localities where the first well was, to all intents, a failure. The excitement that has pervaded the State is largely due to the sensational and exaggerated reports that have been sent out from the points where drilling has been done, by persons gathering news for the press. To one deriving his information from newspaper paragraphs alone, the inference would be warranted that north-western Ohio is one great pool of petroleum, charged with high-pressure gas, and ready to flow out in streams of fabulous value wherever the drill is sunk to the rock that contains it. Much of the production, especially of gas, has been exaggerated a score of times, and some of it even hundreds of times. In one instance, a well was credited in published accounts with 385,000 feet of gas per day, where the measurement showed 1270 feet. The exaggeration is not, as a rule, intentional, but it results largely from the unfamiliar character of the facts. It will doubtless diminish as knowledge of the subjects becomes more general.

The remaining horizons of oil and gas will be very briefly treated in this review. There is but one of commanding importance.

SECTION V.—THE BEREA GRIT AS A SOURCE OF OIL AND GAS IN OHIO.

The stratum here named holds as central a place in the oil and gas supply of eastern Ohio as the Trenton limestone does in north-western Ohio.

As already described, it is a sandstone formation of medium grain, ranging from 5 to 100 feet in thickness, and is remarkably persistent. Its identification under cover is rendered easy by the character of the strata associated with it. It always has a black shale roof and often a red shale floor. Moreover, it is the last regular sandstone to be passed in the rocks of the State in descending order. Its outcrop from Cleveland west and south passes through Cuyahoga, Lorain, Erie, Huron, Richland, Crawford, Morrow, Delaware, Franklin, Pickaway, Ross, Pike, Highland, Adams and Scioto counties. In Pike, Highland and Adams counties, it attains its highest elevation above the sea, which slightly exceeds 1300 feet. In Richland and Crawford, its outcrops have an elevation of 1125 feet above the sea, and on the shore of Lake Erie an elevation of about 800 feet.

It dips prevailingly to the south and east at a rate of 15 to 35 feet to the mile. Its lowest levels are found under deep cover in the Ohio valley from Marietta to Steubenville. The lowest recorded levels are about 800 feet below tide. Its vertical range is thus seen to be not less

than 2100 feet. It is geologically due in 50 counties of Ohio, and it is entirely safe to say that it is present in every one, inasmuch as its presence has been proved in all of those in regard to which a question might most easily be raised. In a number of the counties where it lies deepest, it has been found in scores and even in hundreds of drill holes. Wherever exposed to view it is almost, if not altogether, destitute of organic remains, and its stock of oil and gas is undoubtedly derived from the great mass of bituminous shale by which it is everywhere underlain. It is like all other oil rocks, a repository of salt water as well. The brine derived from it has been the sole reliance of some of the best salt works in the State in years past, and it is still used at one important center of salt production in the State.

At certain points, the Berea grit has proved to be a source of oil and gas when under the lightest possible cover. The well-known oil-fields of Mecca and Grafton furnish instances of this sort. In the first of these fields more than 2000 wells have been drilled, none of them having a depth of more than 50 or 60 feet. In many of the wells there is no cover whatever for the Berea grit but bowlder clay, the lower portions of which are saturated with oil.

It thus appears that the natural shale cover of the sandstone was all eroded in distant ages. Before this took place, the stratum must have been charged with oil. While lying exposed as a surface-rock, oil must have constantly oozed from it, as we find oil and gas escaping from certain outcrops now. But when the nearly impervious beds of bowlder clay had once more formed a cover, accumulation of oil was resumed in the rock, and thus the somewhat scanty stocks that have been drawn upon for the last 25 years have originated.

The oil of the Mecca field has lost most of its volatile products through the light cover by which it has been protected, and it now has the unusual gravity of 26° to 28° B. It is a lubricating oil of excellent quality, its price ranging higher than that of any other natural oil in market. The present product is limited to a few hundred barrels in a year. The Berea grit at Mecca is about 850 feet above sea level.

In the town of Grafton, Lorain county, a production of similar character was maintained for a number of years. The Berea grit here retains 50 to 75 feet of its normal shale cover, but the oil is still a very heavy oil, similar in quality to the Mecca oil. Several hundred wells have been drilled during the history of the field, but none are productive at the present time. The Berea grit at Grafton is about 650 feet above sea level.

As the Berea grit takes heavier cover, it becomes a source of larger production. It has yielded a good deal of gas at several points when found from 400 to 600 feet below the surface. Oil is also produced by it abundantly under the same conditions. The absolute level at which it is found seems thus far a matter of indifference so far as the production of gas and oil is concerned. It has been found to produce one or both in important quantity when it lies 800 above and 750 feet below sea level.

Two or three fields of special interest will be very briefly treated.

THE EAST LIVERPOOL GAS-WELLS.

The gas-wells of this region, viz.: the Upper Ohio Valley, are more widely known than the importance of their supply would lead us to ex-

pect. The utilization of natural gas for household heat and light was effected here in 1874, and has been maintained ever since on a somewhat restricted scale. The village streets have been lighted with natural gas also for the same period.

The gas is obtained from shallow wells, ranging from 425 to 475 feet in depth. The absolute level of the oil-producing rock is about 250 feet above sea level.

The structural features of the field are well marked. A low fold, apparently the Fredericktown anticlinal of White, traverses the strata of the region, lifting the conglomerate coal-measures so as to almost expose their lowest beds. From this point southward, the dip of the strata is unusually rapid. Between East Liverpool and Steubenville, a distance of 25 miles, there is a fall of nearly 850 feet.

Gas was discovered here in connection with salt water, in the widespread search for oil that extended through the country in 1859 and 1860. A small amount of oil was found here, and at Smith's Ferry, a few miles above East Liverpool, an important field, which maintains a small production to the present time, was then developed. The salt water was turned to account for salt manufacture, and after the Kanawha Valley fashion, the accompanying gas was used in the evaporation to some extent, but it was not until 1874 that the gas began to be used for other purposes, as heating, cooking, etc. East Liverpool is a pioneer town in these later applications of natural gas. It was first applied to the burning of pottery here.

The section passed through in reaching the Berea grit is characteristic. The Cuyahoga shale is a homogeneous mass of light-colored shale, 200–250 feet in thickness, always underlaid by the Berea shale, dark or black in color, and 20 to 40 feet thick. The last named stratum makes the cover of the Berea grit, which seldom exceeds 20 feet in thickness, and which is often reduced to less than 10 feet.

The supply is very moderate at the present time. The largest well yields about 35,000 cubic feet per day, and others fall as low as 10,000 cubic feet. Even this production can be maintained only by scrupulous care and attention. All the wells that are used are pumped for salt water once and often twice in a day. A few gallons of brine are removed with each pumping, but were it not for this constant removal, the brine would soon overpower the gas and the supply would become extinct.

The gas company keeps five wells in operation. They supply 50 or 60 families, and they also light the streets of the town. The lights are not extinguished through the day. The present supply runs short in severe weather.

The potteries have made repeated and earnest efforts to secure large and vigorous supplies, but the rock has thus far proved obdurate. It will only yield household fuel.

The gas has but little odor, and accidents of the usual character have resulted from its leakage.

The field has been greatly injured by the overcrowding of wells, 5 or 6 being located on a half-acre, and also by neglect or abandonment of wells already drilled. There is a good degree of permeability of the oil-rock, as is shown by various facts, and one neglected well pours its accumulating brine into those nearest to it.

THE NEFF GAS WELLS.

A series of wells drilled for oil twenty years ago in the valleys of the Kokosing and Mohican Rivers, in the north-western corner of Coshocton county and in adjacent territory, has become widely known through the large production of gas from two of the wells and the continuous production from several others, and through the utilization of the gas in the manufacture of lamp-black in the large way, an important and quite widely-extended application which, so far as is known, originated here. The manufacture is still maintained at this point in considerable force.

The whole enterprise in the way of development and use has been under the management and control of Peter Neff, Esq., of Gambier.

Quite a full account of the wells and of the early stages of the lamp-black manufacture is given by M. C. Read, Esq., in Geology of Ohio, Vol. III, page 340, etc.

Mr. Read referred the oil-rock to the horizon of the Berea grit, and established the probable presence of arches or similar structural derangements in the series at this point, and in the neighborhood the normal dip of the oil-rock being found to be reversed in some of the wells.

The Berea grit lies from 550 to 600 feet below the surface of the valleys, and between 250 and 300 feet above tide-water. Oil has been produced from some of the wells in small quantity; all of them yield more or less salt water. Two of the number proved to be very energetic gas-wells of the geyser type, but the gas has been gradually reduced by the salt water. The three wells that are now the dependence of the lamp-black manufacture are comparatively small producers, and need constant attention in the way of removing the brine that accumulates in them. They are pumped each day for this purpose.

The field certainly shows some promise as a gas-field. Further developments conducted in the light of our recently acquired knowledge of gas and oil accumulation, might fairly be expected to find some points at which the gas would not be so closely followed and hard pressed by salt water. The chief drawback is the distance of the location from any center of established industries that could make use of a large production.

The wells were drilled for oil, as has been said, and great disappointment was experienced when only noisy and ungovernable gas-wells were found. The discovery of such stocks of gas to-day would create a greater interest than any ordinary oil wells in most parts of the State. The disappointment now is when gas is missed and oil is found in most of the explorations in progress.

THE MACKSBURG OIL FIELD.

This is the only important oil-field of the eastern half of Ohio at the present time. There are four productive sand rocks in this field, but the interest centers in the Berea grit. This stratum was first struck here in 1877, the first well yielding only dry gas. In 1878, the first oil well was obtained in the Berea, a ten-barrel flowing well being struck by George Rice, Esq. In 1882, a well flowing 100 barrels per day was obtained, and the attention of Pennsylvania oil-producers was forthwith definitely turned to Macksburg. It speedily became a factor in the general market,

and has produced since that time as much as 3000 barrels per day for a maximum. Its yield for 1885, was over 600,000 barrels. Its present output is about 2400 barrels per day. Over 400 wells are now producing, and the average yield is about 6¼ bbls.

The Berea grit is found here in a normal and unequivocal section at 1450 to 1500 feet below the valley levels. The peculiar structure brought to light by a careful study of the field has been adverted to on a preceding page. It was first noted and worked out in a preliminary way, by F. W. Minshall, Esq., of Parkersburg. Lines of level were afterward run over all the field by the Geological Survey, and Mr. Minshall's reading of the stratum was confirmed at every point.

The leading facts are as follows: In the vicinity of Macksburg, the light, south-easterly dip of the strata is found to be interrupted, and for nearly a mile in the general direction of the dip, a terrace-like structure prevails. All of the strata of the exposed section from top to bottom, and all that are ever reached by the drill as well, are equally affected by this structural irregularity.

It is this terrace which constitutes the Macksburg oil-field. Oil was found here 20 years ago in shallow wells from 200 to 300 feet deep in the Buffalo (Upper Mahoning) sandstone. But adventurous drillers, one after the other, struck new sources of oil. A second oil sand was soon discovered at 500 feet, and a third at 700 feet. Finally, as before stated, the Berea grit was found 1300 to 1500 feet below the surface, holding a stock of oil large enough to make the Macksburg field for the first time a factor in the general market.

But the shallow and the deep productive wells are alike definitely limited to the terrace that has been described. In other words, four oil-sands become productive in the same area when the structure is found favorable. That these several horizons do not communicate with each other is evident from the fact that the oils which they severally produce differ from each other in gravity, in color and in chemical constitution.

The depth of the Berea grit in the terrace below sea level is 735 feet. Of twenty-four wells, distributed through 4 square miles of territory, sixteen found the Berea between 733 and 737 feet below tide, and six found it by their records to be exactly 735 feet below tide.

On the north-western margin of the terrace, at elevations of 728, 720, 713 and 704 feet, gas is found but no oil. Several hundred wells have now been drilled on all sides, and the terrace which stands revealed by the engineer's level is alone found productive.

THE WELLSBURG GAS FIELD.

A gas field developed in the Ohio valley, between Steubenville and Wheeling, demands brief mention here. It embraces territory on both sides of the river, but the center of the production is at and near Wellsburg, W. Va., and the field is best known from this locality. The search for gas in and around the chief manufacturing centers of this part of the valley, as Steubenville, Martin's Ferry, Wheeling and Bellaire, has been

very resolute and persistent. More than 50 wells have been drilled here within the last 3 years, the average cost being at least $3,000. The manufacturing industries of this region are mainly in the lines of iron, glass and clay, and it is precisely these industries that are most affected by the introduction of the new fuel. The manufacturers of this district have recognized the absolute necessity of securing natural gas from some source to maintain themselves in the field, but thus far they have succeeded only in demonstrating that they have no home supply except in a comparatively limited range, and that unfortunately at a considerable distance from the points where the demand is most urgent.

In December, 1882, a gas well of great vigor and promise was drilled at Wellsburg. It is known as the Barclay Well, No. 1. Gas was found all the way down in the descent of the drill, but at 1277 feet a great flow was struck. This flow came from the Berea grit, which was found here 10 feet thick, and under 400 feet of Cuyahoga and Berea shale, above which were 250 feet of the pebbly series of the Waverly and coal measure conglomerates. Under the Berea at Steubenville, the drill descended through 800 feet of Ohio shale without profit. This pioneer well served to accredit the field, but it has rendered comparatively little service in other ways. It blew its great volume of gas into the air for nearly a year, and through various causes lost much of its initial energy. It was then "drowned" by the flood of 1884, and since then has never recovered its pressure. A measurement made of its flow by the anemometer in July, 1885, showed its daily yield to be 30,620 feet.

A second well drilled very near it in April, 1883, known as the Barclay Well, No. 2, has proved a fairly vigorous producer. Its yield in July, 1885, was found to be 469,000 feet per day.

This immediate location has been ruined, however, by the crowding of wells together, and by the neglect of some of the number. The territory is overrun with salt water, and no longer is counted valuable.

Other wells, the noted Dalzell well among the number, were soon added to the list, and for several miles on both sides of the river, drilling went forward on a large scale. The Ohio side was vigorously worked, and wells of some promise were struck at Brilliant, but their life has proved short.

In fact, the entire supply of the district is reported as running low, and the field fails to fulfill its early promise.

Of the eight wells drilled at Steubenville, all have proved virtually failures.

So far as present knowledge goes, there is but one source of petroleum in valuable quantity and of high-pressure gas available to north-eastern Ohio, and that source is the Berea grit. The statement cannot be made quite as strong for the south-eastern quarter of the State, inasmuch as the Waverly Conglomerate, and several strata of the conglomerate coal measures, and also of the upper division of the coal measures furnish, at times, both oil and gas in valuable amount, but when all is said, the Berea grit outranks in importance in these respects all the rest combined. The stratum that yields the Macksburg oil and the Wellsburg gas is the only one on which either the oil-producer or the manufacturer who is seeking for natural gas can afford to make much outlay in that portion of the State.

In all the localities of north-eastern Ohio in which the Berea grit is found barren or but feebly productive, home supplies of high-pressure

gas are not to be expected, and while in south-eastern Ohio there are one or two chances besides those furnished by the Berea grit, and which indeed, must be taken before the Berea grit is reached, they are too uncertain to inspire confidence or to warrant large expenditure. In point of fact, there is at the present time no production of either oil or gas in the eastern half of Ohio that is not derived from or that does not draw its value from the stratum under consideration. The last clause refers to the production of the upper oil-sands of the Macksburg field. By themselves, these last-named supplies would be insignificant, but in conjunction with the oil from the Berea grit, they acquire new value and importance, being able to avail themselves of all the advantages which the latter has secured.

The recognition of these facts would have saved, within the last year, to the towns of north-eastern Ohio, a large amount of money that has been used to no purpose in drilling unusually deep wells in search of natural gas. Their recognition at the present time will discourage for years to come, like large expenditures in random drilling in the same search. Test-wells, involving possible new horizons, when located wisely and when followed with due care and with all available knowledge, will always be in order, but the work that is now going on mainly consists in driving deep holes into the ground, the work being guided by scarcely more intelligence than would be used in turning a wheel of fortune. Chance will always have a considerable part to play in the distribution of mineral wealth of this character, but there is certainly room for other factors in the search for gas and oil in Ohio at the present day. We are able to avail ourselves of a vast amount of expensive investigation by which our own work should be guided, and in many cases restricted for time to come.

As has been already shown, high-pressure gas and oil in "paying quantities" have not thus far been found in the Trenton limestone where its surface falls 500 feet below the level of the sea. This dead-line of the Trenton passes not far from, but generally a little west of the Columbus, Hocking Valley & Toledo railway, through the counties of Wyandot, Sandusky and Wood. From this boundary eastward, until the Berea grit is found under respectable cover, say 300 to 500 feet, there is an interval of 40 to 140 miles in which so far as present knowledge goes, the conditions for high-pressure gas do not occur. The line of the Cleveland, Columbus, Cincinnati & Indianapolis railway, through the counties of Richland, Huron, Lorain and Cuyahoga to Berea, and thence a line running through the central part of Cuyahoga, Geauga, and Trumbull counties to Pennsylvania, will make the eastern and northern boundary of an interval in which the Trenton limestone lies too deep to be available as a source of high-pressure gas, and in which the Berea grit cannot serve such a purpose, either from the fact that its outcrop does not extend so far, or from the fact that it lies too shallow to have acquired large accumulations. To the eastward and southward of this new boundary throughout the eastern half of the State, this persistent stratum is to be counted on as present and ready to take its part as a reservoir of oil in quantity or of high-pressure gas whenever and wherever the other conditions for such accumulation are found. The Trenton limestone is, of course, at still greater disadvantage in this area. Its horizon has dropped so low that no driller has been adventurous enough to find it, and in fact, there is no certainty that we should know it if we reached it. At the center of this old gulf, it is quite possible, perhaps

even probable, that the limestone growths so characteristic of this great stratum along a thousand miles of soundings would be replaced by very different materials. Limestone might well give place to shale or other fine-grained deposits.

The boundary within which the Berea grit may be counted ready to perform its part in furnishing high-pressure gas has been roughly traced from the Pennsylvania line into Richland county. Southward from Shelby, the same boundary would extend along the east line of Morrow county, the western central portions of Licking and Fairfield, the western boundary of Hocking, the eastern boundary of Ross, and the central parts of Pike and Scioto. Through all the portions of the State that lie south and east of this boundary, the Berea grit is under 300 feet or more of cover which consists first of 30 to 50 feet of the black or dark close-grained Berea shale, over which, when the full section is reached, 300 to 500 feet of Cuyahoga shale is found, light-colored, compact, and fine in grain, and almost thoroughly impervious. It is underlain throughout its whole extent, on the other hand, by never less than 300 feet of bituminous shales, which are sometimes condensed into a fairly homogeneous mass, as on the western border, and sometimes interstratified with, and distributed among 5 or 6 times as much lighter-colored, green, gray, or blue shales, as in the interior of the basin. As for the Berea grit itself, it is always a porous rock, though seldom a coarse one. Some of its best work as reservoir for oil and gas is done by it where its grain is below, rather than above the medium grade.

Here then are source, reservoir and cover in perfect order, and on the largest scale, adjusted to large, to even the largest production of oil and gas.

How often do they reach such production? The meager list of localities already given, embraces the important fields that are now known. We have reason to expect that this list will be somewhat, and it is to be hoped, considerably expanded under the explorations that are now going forward.

But it is safe to prophesy that the new fields, like the old ones, will ally themselves in all instances with irregular and abnormal structure of some sort, with broken stratification, with low arches, or in default of folds with the terrace-like areas already described, which in reality are folds that nature began to build but was not able to finish. Throughout how many portions of the main district under consideration, these fortunate misfortunes, these happy accidents of structure are wanting, the drill is constantly making known to us by the negative results of its work.

Within this main area of Berea grit territory, there is no known source of high-pressure gas below the Berea itself. We might well expect some such sources, especially in the north-eastern corner of the State, because the Venango, the Warren, and the Bradford sands of western Pennsylvania, the most remarkable repositories of petroleum and gas yet found in the world, belong in the interval between the Berea grit and the Corniferous limestone, but they appear to have almost or altogether fined out and disappeared in passing to the westward. Obscure hints of sandstones in the underlying shales of the Ohio section are all that we generally meet, and in no case has important accumulation been found in these possible representatives of the great Pennsylvania storehouses.

The Corniferous limestone itself, as has been already pointed out, apparently holds all of the conditions of successful accumulation of petroleum. It has ample stores of oil within itself, it has also ample thickness, and its cover would seem to meet all demands in that respect, but no valuable accumulation has thus far been found in it within the limits of the State.

The Berea grit has shown considerable vigor in past years in the counties of Hocking and Vinton. There are developments going forward now on this stratum in these counties, and also in Perry and Muskingum that will be watched with interest, but there is not yet any well marked productive territory made known.

Before drawing certain practical conclusions for guidance in the future search for oil and gas, from the facts already stated, it will be best to describe the principal remaining horizon of natural gas in the State, albeit it is not a horizon of high-pressure gas.

SECTION VI.—THE OHIO SHALE AS A SOURCE OF GAS AND OIL.

The two main sources of gas and oil in Ohio have now been described, and the approximate boundaries of their productive territory, as shown by recent explorations, have been pointed out. But what of the wide belt of country that lies between these boundaries in Northern Ohio? Is it entirely destitute of oil and gas? Is it by its composition and structure debarred for all time from taking any part in this production?

It may seem like a contradiction after what has been claimed for other districts, and what has been denied at least by implication for this, to assert that within this intermediate area, or at least within those portions of it that lie nearest to the main Berea boundary, there is not only a greater number of gas springs, oil-seeps, and other surface indications than is to be found in any other equal area in the State, but a much larger number of gas wells in steady flow. But this statement can be fully substantiated without antagonizing the claims that have been made for the Berea grit and the Trenton limestone.

The belt of country to which reference is now made, it will be remembered, extends along the south shore of Lake Erie westward from the Pennsylvania line as far as the Huron river, from which point it extends southward to the Ohio valley, with a breadth varying from 15 to 40 miles.

This belt takes in the western outcrop of the Ohio (black) shale, and also the outcrops of the Berea grit and its normal covers, extending eastward and southward until the sandstone has had time to fall 300 feet or more below the surface of the valleys. There must be added to it also, 1000 to 1200 square miles in the north-western corner of the State where the Ohio shale is the surface rock, covered, however, as a rule, by heavy beds of drift.

The main territory thus bounded will be recognized by all conversant with the facts as embracing the most numerous and longest known

gas wells of the State, those namely which have been drilled along the shore of Lake Erie, mainly between Cleveland and the Pennsylvania line There is not a township between the limits named in which one or more successful wells has not been drilled. At many points, wells have been drilled to the number of 6 and more, which are yielding steady and excellent supplies. A few general statements will suffice as to the character of this supply:

1. The gas is of the same character as that found in the Berea grit. It is probably, however, more uniform and constant in composition than that which is yielded by the latter stratum from considerable depths. Its odor is not marked or offensive, and consequently good gas-fitting is required when it is introduced into domestic use.

2. It is without exception, low-pressure gas. This term is relative, not absolute, it is true, and pockets of gas are often found in drilling, to which the statement would not apply, but when the wells have settled down to their normal flow, the closed pressure probably never rises as high as 100 lbs. to the inch.

3. The wells, in like manner, yield but comparatively small volumes. A daily yield of 80,000 feet is as high as has yet been measured. Wells with one-fourth of this production are counted good wells, and many of them range from 1 to 5,000 cubic feet per day. In some cases, storage is effected by small gasometers that receive the gas as it rises and send it out with equable flow.

4. The supply from this source is peculiarly adapted to domestic use, and to this it is for the most part applied, The sharper wells, however, are available for steam production and other like services. To make a really good illuminating gas, it would need to be enriched by a naptha bath, but so far as known, this method has not been used. Street-lamps, yard-lamps, and house-lights supplied by the gas are all in common use where wells are in operation, but the main volume of the supply is for heating purposes. For cooking stoves and ranges, and for ordinary open grate fires it is most happily adapted. The convenience resulting from its introduction for all such uses passes description.

5. The horizons of the gas in the shale have not been determined. At first sight, the gas would seem to be capriciously distributed, but this appearance may be proved deceptive when more opportunities for observation have been furnished. There are always few, and often no recognizable horizons in the shale unless it is covered by the Bedford and Berea formations, and consequently it is difficult or impossible, without careful levelings from well to well, and accurate measurements of dip, a problem which is dependent on, and complicated by the same factors, to determine the relations of the gas-producing horizons, whether widely extended or sporadic. The wells that are now being sunk in the neighborhood of Berea will do much toward answering these questions, inasmuch as they generally pass through the Berea grit and Bedford shale, one or both, or at least stand in such relations to the outcrops of the sandstone, that measurements can be taken from it to the gas-producing beds. The difficulty in fixing upon horizons in the shale itself, and the entire inadmissibility of the old classification of the Ohio shale into Cleveland (black), Erie (greenish-blue), and Huron (black), are well shown in the record of the home well of Mr. A. W. Bishop, of Berea, which has been finished within the last year.

The record is as follows:

Drift beds.	Soil and clay	19 feet.	21 feet.
	Gravel	2 "	
Berea grit			55 feet.
Bedford shale.	Light-colored soapstone, soft	15 feet.	124 feet.
	Hard sandrock	8 "	
	Light-colored soapstone, soft	4 "	
	Red shale	82 "	
	White slate	15 "	
Ohio shale.	Brown soapstone	55 feet.	1120 feet.
	Dark shale	20 "	
	Light-colored slate	350 "	
	Dark slate	155 "	
	White slate	30 "	
	Black shale	45 "	
	White soapstone	25 "	
	Black shale	35 "	
	Light soapstone	30 "	
	Black shale	30 "	
	Light soapstone	15 "	
	Black shale	30 "	
	Light soapstone	215 "	
	White shale, hard	15 "	
	Black shale	15 "	
	White shale, gas	20 "	
	Black shale	35 "	

Corniferous limestone struck at 1320 feet and drilled into 15 feet; total depth of well, 1335 feet.

From the Berea grit to the Corniferous limestone, the interval here is 1244 feet. Question may be raised as to the exact base of the Berea, however. The alternations of shale above noted, and the approximate thickness of the different elements can be learned from the section, but the exact thickness of each element was not an object of curiosity on the part of the driller, and the facts are given in round numbers, as is obvious. The driller distinguished shale from soapstone in his record by the test of hardness. The plastic shales are called soapstones; the hardest and firmest shales at the other extreme in this respect make the slates of this record.

Gas was found in this well at 600 and at 775 feet, and also as noted in the record near the bottom of the shale, but the supply is in fact quite small, all of it being utilized in a single house without meeting even then all demands, but in other wells drilled within 2 or 3 miles, a much more vigorous supply has been reached, and at considerably less depth. Between 700 and 800 feet in depth the most prolific horizon was found at these other localities, and the best supplies came from a considerable range in the rock. As the drill descended foot by foot, new supplies were released.

6. The influence of structure, or in other words, of breaks or arches of the beds on the accumulation of gas in the Ohio shale is presumably the same as in the case of the reservoir that so often overlies it, viz.: the Berea grit, but by reason of the same class of facts that obscures the problems of dip and gas horizons, the assertion that such is the case must be made in qualified terms. In a few examples, and notably in the

Mastick well, in the valley of Rocky river near Berea, a small but distinctly marked break in the shales occurs as a rudimentary anticlinal, the direction of which is N. 40° E. Along this break, gas has always been escaping in considerable quantity. Salt water rises with the gas, the locality being one of the brine licks of early days. When the drill descended along the crown of this axis, gas was found all of the way down, but the chief supplies came at 400 and 500 feet. Two months after the well was drilled, its outflow was found by the anemometer to be 21,643 cubic feet per day. It apparently maintains this production to the present time.

While the shale is so charged with oil and gas that a dry hole drilled into it at any point would probably show some outflow of gas, still it seems probable from the facts of distribution of the larger wells that the same determining causes in minor structural disturbances that connect themselves with our other supplies, will be found here when proper opportunities for observation and study have been secured.

7. The gas yielded by the shale seems fairly persistent. General J. S. Casement's first well at Painesville was drilled 16 years ago, and it still yields more than gas enough for ordinary household use. The gas springs of Fredonia, N. Y., have been used for illumination since 1821, and though the original supply has been disturbed by the drilling of wells within their area, there is no reason to doubt that it would have continued indefinitely if it had not been so disturbed. By the drilling of the wells referred to, the production of the original tract has been largely increased.

It seems probable that gas is constantly produced in the shales, not by the decomposition of the organic matter that they contain, a process which, so far as we know, can be effected only by destructive distillation, but by the simpler change of the petroleum with which the shales are everywhere charged into gaseous products. The theory of spontaneous distillation of petroleum from the organic matter of the shales has been already discarded, but the process here suggested has considerable superficial resemblance to it.

The permanency of gas supplies in the various sandstone reservoirs is in most cases connected with the amount of salt water produced by the gas rock. If the supply of brine is considerable, the wells can, with difficulty be maintained, and in only a few cases can the wells be left to themselves. In most cases they are maintained by unremitting care in removing the salt water as it accumulates. While brine is not wanting in the shale gas wells, it is by no means as troublesome an element as in the sandstone wells. There are very many cases where a well is drilled dry and remains dry permanently.

8. The value of the gas supply that is now under consideration has never been properly estimated by the districts within which it can be secured. By its character, it is mainly limited to household use, but, as has been shown, for this purpose it can scarcely be improved when found under favorable conditions. The wells required to reach it are easily drilled and cheaply equipped. They require but little casing, and sometimes none their maintenance involves neither trouble nor expense, and their supplies are fairly maintained. There can be no question but that the shale gas wells outlast the high-pressure wells of the sandstone reservoirs.

The problem of using low-pressure gas in town supply, the sources being within the town, has already been solved with a measure of success in East Liverpool, and also in Fremont, but the Berea Pipe Line company has undertaken to transport gas of this character from wells that are 2 or 3 miles distant. The result of this undertaking will be looked for with interest, and if it proves successful a new impulse will be given to the development of the shale gas field.

There are farms by the thousand throughout these areas in which gas can be found in ample quantity for household use, and where the supply can be reasonably assured, by the drilling of occasional new wells, for certainly a long term of years. Such farms may come to be valued as much for this as for other and more easily recognized resources.

A word needs to be said in regard to the area of Ohio shale that occupies three or four of the counties in the north-western corner of the State. This formation represents only the lowest beds of the great shale series. Not more than 150 feet have been found in any section thus far reported. It is in almost all cases deeply covered with beds of drift, sand, gravel and bowlder clay being variously interstratified.

When penetrated by the drill, as in the wells that are sunk for water or more recently for gas, this shale stratum often sends out notable quantities of gas. The main supply seems to be derived from near the base of the shale.

Gas is also found frequently in the drift beds overlying the shale. There is another possible source for this supply, but it is quite likely that in some instances, gas from the shale has been accumulated in the gravel where the latter is covered with bowlder clay. All the conditions for gas accumulation seem to be met by this order of arrangement.

The stocks of gas in the north-western shales cannot be as large or as enduring as those already described in the shales of the eastern area, on account of the small thickness of the formation, but it may still be found that there are some accumulations that can be used with profit in the way of household supply. Persistent stocks of high-pressure gas are scarcely to be expected here.

SECTION VII.—THE CLINTON, MEDINA, HUDSON RIVER, AND UTICA SHALES AS A SOURCE OF GAS.

Between the limit at which the Trenton limestone has thus far been found largely productive, viz.: the line of 500 feet below the sea level, and the western boundary of the Ohio shale in its main outcrop, there is a number of counties, as Ottawa, Sandusky, Seneca, Wyandot, etc., with parts of others to the east of their respective boundaries, in which it seems hopeless in the light of all explorations made to the present date, to look for oil or gas in the Trenton limestone. The wells of Fremont and Carey have already been referred to, but since the previous statements in regard to them were put in type a few new facts as to their production and character have been obtained. Three wells have been drilled at Carey, the first of which now yields by anemometer measure, 27,163 feet per day. The well shows a closed pressure of 405 lbs. The second well yields 21,375 feet per day. The third well appears at present to be a fail-

ure. The first and second both obtained notable supplies of shale gas. It was especially strong in the latter, but the present production is largely from the Trenton.

At Fremont, as previously stated, eight deep wells have been drilled. The best of these deep wells is well No. 2, of the Natural Gas Company. It yields by anemometer measure, 18,720 feet per day, and is used in the lines of the company. The best of the three shallow wells lately drilled in the town is the Ames well, the daily production of which is 16,473 feet. This well gets all of its gas from the Clinton limestone and shales, the Niagara shale making the cover. Wells directed to this horizon need not be more than 500 feet deep, and they can be drilled and equipped for less than $1,000. The discovery of this supply is of great importance in this part of the State.

A well has been brought in at Oak Harbor, Ottawa county, within the last few days, of much larger volume than any of those last described. Measured in the first week of its flow, it makes a record of 78,250 cubic feet per day. Its pressure rises to 101 lbs. when the well is closed 40 minutes. The gas is derived mainly but not entirely from the Trenton which was reached at a depth of 1300 feet, or 724 feet below tide. The rock was shot with 60 qts. of nitro-glycerine. This well comes much nearer to being an exception to the 500-foot line already laid down, than any other in the field. If it maintains its flow, and if other wells of equal volume are found, a gas field of some importance will be established here. A little oil of $38\frac{1}{2}°$ gravity is found with the gas. The town is enterprising and the advantages of natural gas, if an adequate supply is reached, will be turned to the best account.

It has already been shown that low-pressure gas is available in some localities in the Clinton, Medina, and Hudson river shales. The experience of Fremont has demonstrated this fact, and it is a point of considerable importance. Wells can be drilled to this horizon in the western part of the area referred to, without great expense. The gas found in the three wells drilled at Sidney is all derived from these shales. It has not proved persistent at this point, but a considerable volume was yielded by the second well. Two months or more after its completion its daily flow was found to be 39,744 feet. The supply is one that needs further investigation in this region.

As has been previously shown, there have been notable quantities of gas yielded throughout the Findlay district from these shales from the first development of this field. The 700-foot horizon at Findlay, has in particular, been found a vigorous source. In other fields, this alone would be counted a very successful supply. In the Briggs well, the upper vein is cased off separate from the Trenton gas, and the former has been found by measurement to exceed 200,000 cubic feet per day.

The "blowers" of gas struck at Springfield, Piqua, and at many other points, which have raised such extravagant, but short-lived expectations, all come from these sources.

It now appears as if south-western Ohio were mainly shut up to these rather feeble and uncertain sources.

On the western side of the general district now under consideration, through the counties in which the Corniferous limestone has its outcrops, viz.: through parts of Erie, Seneca, Wyandot, Crawford, Marion, Delaware, and Franklin, and through those parts of Paulding, Henry, Wood, and Lucas counties, in which the same formation makes the sur-

face rock, it is hard to see what sources of oil or gas are available. The Trenton limestone is found unproductive, and the Medina and Hudson river shales lie too low to allow their supply which is at best so moderate and restricted, to be sought for with any promise of profitable returns. The entire series of Devonian and upper Silurian limestones would require to be cased in such wells, and the expense would be large.

The remaining horizons of gas and oil in the geological scale of the State, which are found mainly in the sandstone strata of the Carboniferous and Subcarboniferous ages, and notably in the Waverly and coal measure conglomerates must be passed without further mention here. There are no very important supplies at present derived from any of them, but in past years, the oil production of the Cow Run field, of Washington county, and of other adjacent fields attained respectable proportions, and even now considerable oil is found in the upper sandstones of Macksburg, as has been previously stated.

One other source of gas, however, is so common and so misleading throughout three-fourths of the State, that a few words must be devoted to it here. It will be briefly discussed in the concluding section of this abstract.

SECTION VII.—THE GLACIAL DRIFT AS A SOURCE OF NATURAL GAS.

Nearly three-fourths of Ohio are covered with the deposits of the Drift, the most recent, but the most anomalous and perplexing of all of our geological formations. These deposits consist (1) of bowlder clay, a tough, compact and mainly unstratified deposit, containing fragments of rocks, from the size of pebbles to blocks of many tons weight, derived from regions to the north of where they are found, and which are quite generally smoothed and striated in such a way as to show that they have been subjected to a violent abrading agency; (2) of gravel and sand, clean and distinct, in pocket-like deposits, or variously intermixed with clay and that are included in or covered by the deposits of bowlder clay; (3) of stratified beds of sand, gravel, and fine clay, that are obviously of later age than the bowlder clay, and that owe their arrangement to deposit in water.

These beds taken collectively are of considerable thickness, especially in the north-western portion of the State. The drilling that is now going forward is revealing to us as nothing else could do, the vast amount of these drift accumulations. It is not uncommon to find sections of drift 75 to 100 feet thick before the bedded rock is reached, and measures of 150, 175 and 200 feet have been occasionally found. The most surprising section ever reported from the drift deposits of Ohio, has, however, recently been found at St. Paris, Champaign county, on the line of the Chicago, St. Louis & Pittsburgh railway (mention is made of it on page 27 of this report, but before the bottom of the deposit was reached). This town has an elevation by railroad levels, of 1237 feet above the sea. It is 353 feet higher than Piqua, and 195 feet higher than Urbana, the elevations being counted from the stations of the railroad above named.

In the well recently drilled at Urbana, the drift deposits were found

155 feet deep. The bedded rock is therefore here about 900 feet above sea level. At Piqua, the Miami river is running on rock at about 860 feet above the sea.

But the drillers at St. Paris found no bedded rock until they had driven pipe to 510 feet below the surface. In other words, the bedded rock here lies at 727 feet above the sea, or 140 feet lower than the rock at Urbana, and 170 feet below the present bed of the Miami at Piqua. This is, without doubt, by far the thickest bed of drift yet reported in this State. At 400 feet a considerable amount of vegetable matter, tree trunks and branches and black soil, was found. The wood is red cedar. "Mussel shells" were reported to be found with the wood, but no opportunity was found to verify this observation

Attention was long ago called to the fact that the Miami river is running in a rocky channel most of the distance from Sidney to Dayton, and that this channel is therefore a recent one, worked out since the close of the glacial period. A part of its old channel in Clarke county was also pointed out, but though it was easy to see that the original valley was to be looked for to the eastward of its present course, no one would have dared to locate it under the highest ridge in all this part of the country. Yet it is just this which the drill has now demonstrated, and St. Paris is found to be situated directly above the ancient channel of the Miami river. Other points will undoubtedly be found in this buried channel by which its course can be determined.

The fact that vegetable matter in the shape of cedar wood was found included in the bowlder clay of St. Paris has been mentioned in the account above given. It is scarcely necessary to state that such material is of very common occurrence in the bowlder clay or just beneath it, on or near the surface of the bedded rock, in many portions of the drift covered areas. These deposits often render the water which is associated with them foul and unfit for use. In some parts of the country they are known as "Noah's barn-yard." There are counties of Ohio in which a c nsiderable proportion of the wells that are dug strike this buried timber and these other accumulations of vegetable matter.

These facts are mentioned here to explain the origin of a large number of the "surface indications" of natural gas which are so attentively noted and so frequently reported at the present time.

This buried vegetation in a great number of instances gives rise to light carburetted hydrogen or marsh gas, which is the chief constituent of natural gas as well as of the fire-damp of coal mines. No line of division can be laid down between marsh gas, fire-damp, and natural gas. They are one and the same thing in substance. The gas escapes slowly from the drift beds, coming up with the water and giving rise to the weak gas springs that can be found so widely scattered through the State.

The gas is sometimes found in such quantity and with so steady a supply that it can be utilized for household service. It has been so used at a number of points in Champaign county, Illinois, for many years. The gas when enriched by passing through a naptha bath, is made available for household light as well as heat.

Surface indications of this sort are obviously of no value as guides to the great reservoirs of natural gas which our communities are seeking so earnestly at the present time. But it is the drift gas and the shale gas that are most frequently found and on which large expectations are often based. In other words, there are "surface indications" and "sur-

face indications." Indications like those that Findlay gave from the date of its occupation to the discovery of high-pressure gas would no longer escape notice, now that it is seen what they stand for, but there are other points by the thousand in which only the weak outflow of gas escaping from vegetation which is slowly decaying without the access of the air, is to be noted, and these, as already stated, are without significance. The "surface indications" of the outcrop of the Ohio shale are also without significance so far as high-pressure gas is concerned. Small outflows are the rule rather than the exception throughout the whole extent of the outcrop of the black shale. To repeat what has been said already, natural gas is one of the common and widely distributed substances in nature, and a little of it at least can be found anywhere.

GENERAL SUMMARY.

In the preceding pages, it has been shown that there are two main areas of the State, involving distinct and widely separated geological horizons, in which high-pressure gas and large production of oil are now found. It has also been shown that there is another well-bounded and widely extended area in which low-pressure gas of excellent character and fairly persistent in its flow can be obtained. There are also two subsidiary areas of low-pressure gas, less developed and less extended, and of much less value.

These several areas can be shown in tabular form, thus:

High-pressure gas.	Berea grit territory. Trenton limestone territory.
Low-pressure gas.	Ohio shale, main outcrop. Ohio shale, north-western outcrop. Clinton, Medina and Hudson River shales.

1. The Berea grit territory occupies 36 counties of eastern Ohio in whole or in part, with the boundaries given on a preceding page. Through all of this area, the Berea grit is due at a depth of 300 to 2000 feet below the surface. It is everywhere roofed with a thin bed of black Berea shale, which in turn is covered by 200 to 500 feet of the light-colored Cuyahoga shale. It everywhere overlies a great thickness of Bedford and Ohio shales, the former of which is often red, and the latter of which always carries a considerable proportion of dark or black bituminous shales, interstratified with lighter-colored bands. There is a wonderful uniformity in this entire series throughout the area named, as has been shown by a large amount of drilling. The productiveness of the Berea in oil and gas cannot therefore depend on the composition of the series, for in that case all would be productive. *It must depend on structure*, and in the few places where it has been found productive, abnormal structure has been, in almost every instance, already detected.

The Berea grit is not the only petroliferous horizon in this area. The coal measure sandstones and the Waverly conglomerate sometimes

yield oil and high-pressure gas, but all these must be passed before the Berea is reached.

The practical deduction from these facts must be emphasized. The Berea grit is the lowest horizon yet found in these counties in which gas or oil is held in quantity. *There is therefore no wisdom in going below it in the search.* If it is found barren or full of brine, there the drill should rest. The particular territory tested must be counted unproductive. It is especially impracticable to seek to reach the other great horizon of high-pressure gas, viz.: the Trenton limestone, within the Berea territory.

This has been attempted repeatedly within the last year with great outlay and with no valuable return, except in the way of geological information. The scheme is essentially impracticable. Beneath the Ohio shale, which ranges from 400 to 1800 feet in thickness, is the great series of Devonian and Silurian limestones. This series ranges from 700 to 1100 feet in thickness. It is full of salt and sulphur water which must be cased off. This requires casing from 1000 to 2000 feet deep. After the limestones are passed there are 800 to 1200 feet of shales due, and there is thus far not a single fact to warrant the expectation that if the Trenton is reached it will hold any valuable contents. It was found to lose its important stocks as it sunk from 300 to 500 feet below the sea level, and now that it is 1000 to 2000 feet below, we have no warrant for expecting any value in it, *from any facts that yet appear.*

In the shales underlying the Berea, low-pressure gas can sometimes be obtained, but supplies of this character properly belong to shallow wells, and cannot be managed profitably where deep drilling is necessary. At all events they are not of value enough to be sought by deep drilling.

In the 36 counties already indicated, there is nothing to warrant the sinking of a well below the level of the Berea grit. The scores of instances already in hand demonstrate this fact and new examples are accumulating every day. Large outlays may be avoided in many wells already projected or begun, if this counsel is heeded.

Practically, the Trenton limestone is as effectually cut off from the Berea grit territory as the Berea grit is from the productive district of the Trenton limestone. In the latter case, the stratum to be sought for is a half-mile in the air; in the former, it is a half-mile under ground.

Although this sandstone stratum has been weighed in the driller's balance and found wanting at a great number of places in the State, there is yet ample room for exploration, and the best of reason for believing that much more imprisoned power will sooner or later be released from its widely extended store house.

2. The Trenton limestone has been found a source of very valuable stocks of oil and gas in three counties of the State, viz.: Wood, Hancock and Allen, and there is much reason to expect that Auglaize and Hardin and possibly Shelby, Logan and Champaign counties may prolong the productive belt southward. The north-western boundary seems already fairly well defined: the north eastern boundary less so, by reason of the small wells at Fremont, Carey, and Oak Harbor. The southern boundary *which has not yet passed the Allen county line*, will be looked for with great interest. The Trenton Limestone shows, as far as developed, absolutely no such structural lines as are found in the Pennsylvania oil fields, and the recognition of such lines in the present state of our knowledge is a delusion if not a snare. But as in all such cases, only the successes are remembered; the far more numerous failures pass out of sight. The Find-

lay break is the only pronounced line of structure yet apparent, and this bears North 14° West.

There has not been found thus far in the experience of the entire field the slightest advantage, so far as oil or gas is concerned,in drilling more than 50 *feet into the Trenton limestone*, and many thousands of dollars have been already spent in these tedious and profitless descents. More money is now being expended in the same way. It is not to the driller's interest to continue the work, as the chances for loss of tools are many, but the companies are generally unwilling to accept a foregone conclusion, and to recognize their venture as a losing one until they have made it more so.

3. The Ohio shale gas belt is the most reliable in its response to the drill of any of the districts named, but it promises only low pressure wells. It must be taken for what it is. It is vain to seek the lower horizons through it. The expense of casing through the limestones would be too great for the gas that is produced at or near the Medina horizon if it could be found. All that has been said in regard to deep-lying Trenton under previous heads, applies here without qualification. In other words, *each division of the State is limited to its own horizon.*

4. So far as can now be seen, there are large districts of Ohio, and especially its south-western quarter, where high pressure gas does not exist. More trials will be required to settle the character of particular fields, but there is nothing to warrant exploration on the large scale.

CONCLUSION.

The facts pertaining to the supplies of petroleum and natural gas in the State as at present understood, have now been briefly summarized. Special attention has been devoted to the last named of these closely connected substances, on account of the great practical interest that is taken in it at the present time. The progressive nature of geological science is kept distinctly in mind in what has been presented, and the consequent provisional character of many of the conclusions that are drawn in such fields as this, but it has been deemed better to present these conclusions as they now appear, rather than to wait for a larger and more complete set of facts which could be gathered only by costly investigation, part of which can well enough be spared. By presenting these facts and conclusions at this time, it is hoped that much of the indiscriminate, enthusiastic and often ill-judged drilling of deep wells that is now going forward in the State will be checked, and that a calmer and more intelligent frame of mind will be brought to bear upon the search for these buried treasures. The prevailing state of mind in regard to this search is not a very reasonable one. To start the drill and sink it "deep enough" is the proper policy in the average judgment. By "deep enough" is generally meant 2000 feet or more. A railroad 100 miles in length, from a manufacturing center to a coal field, may prove a profitable investment to the company that builds it, but it would be irrational for another company, inspired by the success of the first, to expect that another road run out from the city at random or even on "a north-east line," if only 100 miles long, would prove equally remunerative. All

depends on what it finds at its terminus in the way of profitable business. The aim has been in these pages to show what *is* "deep enough" in the several districts of the State, and to suggest proper termini for the wells that are going down.

There is really no such haste in this search for oil and gas as many communities seem to think. These stocks of buried heat and power have been for many thousands of years where they are, and substantially what they are, and they will remain available for thousands of years to come if left undisturbed. They will be worth more in coming years than they are now. They are safe in their present reservoirs. At least they cannot be drawn upon by drilling done at any great distances. It is a crime against the State to unlock them before any use is provided for their contents.

The conservative tone of this abstract, it is well understood, will not be as acceptable as a more hopeful view would be, for people like to be advised to do what they have made up their minds to do, but "the facts are what they are." What good can come to us from shutting our eyes to them?

Exploration should go forward on many sides, but cautiously and economically, and with an intelligent recognition of the conditions of the problem, and above all, its burdens should be properly distributed.

It will be borne in mind that this paper is an abstract of more extended discussions of the several subjects herein considered, which are to be presented with other material to the Legislature, on February 1st, 1887, under the title of Volume VI, Geology of Ohio. All errors of statement that are found herein can be corrected in the more deliberate publication that is to follow, and the conclusions drawn from the work already done will then be confirmed, extended, modified or set aside by the much wider series of facts that are coming into our possession.

APPENDIX.

MEASUREMENT OF THE FLOW OF GAS WELLS.

The determination of the amount of gas yielded by vigorous wells is a problem that has not hitherto been adequately solved. No methods at least have been found to be in common use at the centers of gas production, except vague and uncertain calculations based upon the pressure when a well is closed for a given period. The fallacy of this method has already been exposed. All wells of a district, great and small, attain, finally, the same closed pressure. The fact that wherever high-pressure gas is obtained at all, there is generally a surplus, probably accounts for the neglect of this question hitherto, on the part of those who control the large supplies. Nice measurements have thus far been superfluous, and, in fact, gas has not been thought of by definite volume, but only by the work it will do.

It is easy to see, however, that accurate knowledge of the yield of a well is essential to an economical disposition of its product. As the use of gas in the main fields is extended, and as the supplies begin to weaken, the question of quantity will speedily become more important, and all wasteful methods of supply that may now be in force will be discarded.

The problem of gas well measurement has been taken up by the Ohio Survey, and a method has been devised and worked out by Professor S. W. Robinson, of the Ohio State University, which is simple, easy of application and adapted to wells of every grade, the strongest as well as the weakest.

Space does not suffice to present the method here. An abstract of the chapter prepared for the Survey is to be published in the August number of Van Nostrand's Engineering Journal, and a briefer summary has already appeared in the American Manufacturer. Only the practical application of the method can be given at this point, and this but in part.

To measure the flow of a vigorous well, attach an open tube of convenient length, straight or bent, to a steam-gauge. Hold the open end in the current of gas at the well-head in the line of flow, and note the pressure which the gauge shows in pounds. Add to this pressure 14.6, and divide the sum by 14.6, find the resulting number or that nearest to it in table I. Take from table II the number corresponding, increasing or decreasing proportionately to difference between number obtained by division and number in table I. Multiply the number thus found in table II by 3103, and the result will be the *velocity* of the current in feet per second. To find the *volume* per second, multiply the velocity (in feet) by the area of the pipe (in feet), and to find the volume per day, multi-

ply this result (volume per second) by 86,400 (number of seconds in day of 24 hours). The result will be the volume at a temperature of 60° F., and at atmospheric pressure. Calculations can readily be made for different temperatures.

The tables I and II are given below:

I.	II.	I.	II.
1,035	.1000	1,572	.3742
1,071	.1414	1,620	.3873
1,107	.1732	1,669	.4000
1,145	.2000	1,719	.4132
1,183	.2236	1,770	.4243
1,122	.2449	1,822	.4359
1,263	.2646	1,876	.4472
1,304	.2848	1,930	.4585
1,346	.3000	1,986	.4690
1,389	.3162	2,043	.4796
1,433	.3317	2,101	.4899
1,478	.3464	2,160	.5000
1,525	.3606		

An example will make the mode of application clear:

The pressure noted in the gauge applied to a gas well is 13 lbs. $13 + 14.6 = 27.6$; $27.6 \div 14.6 = 1,889$. The number nearest this in table I is 1,876, and the difference between this and the number found by division is .013, which is one-fourth of the difference between 1,876 and the next higher number. In table II, the number corresponding to 1,876 is .4472. The difference between .4472 and the number next above it is .0113. Add one-fourth of this difference, or .0028 to .4472: the sum is .4500. Multiply .4500 by 3103: the product is 1396.35, which is the velocity of the gas in feet per second. The gas is escaping from a 5⅝-inch casing, the area of which is .1725 of a square foot. The daily yield of the well, therefore, is $1396.35 \times .1725 \times 86,400 = 20,803,168$ cubic feet of gas at 60° F.

This method is applicable with modifications to smaller wells, but in wells yielding less than 1,000,000 cubic feet per day, the anemometer is much the most convenient instrument. The use of this instrument for this purpose was first suggested, so far as is known, by E. McMillen, Esq., of Columbus, and was first applied by him to the measurement of the Adams well in Findlay, in June, 1885. The measurements obtained by this instrument have been compared with other measurements, and their reliability is established.

The large gas wells speak for themselves, and in regard to their value, when fortunately located, there can be no question, if they prove moderately lasting, but there is often no ready means of judging, whether or not a small well is really making a proper return for the money spent in getting it. Measurements of daily flow, like those already provided for, furnish the only intelligent basis for settling such questions.

But even when quantity is determined, we need to know how to interpret the figures, or in other words, we need to know what 5,000 or 10,000 feet of gas will do in heating and lighting, or in making steam. This subject will be treated more fully in the final report, but a few suggestions will be offered here.

Wells drilled for home supply need not be considered at this time. Natural gas in such cases is counted a luxury, and is paid for on that basis, if necessary, but when a well is drilled for town or village use, or

for manufacturing purposes, how large a production must it make to be a safe investment? There are various elements involved—the cost of the wells, the outlay for distribution, and the price at which the gas can be sold. The probable life of the wells must also be taken into the account. A well ought to return the money spent on it, with proper interest, in the course of a very few years. The expenses of the distributing plant, with interest thereon, must also be covered in a reasonable period.

The open flow of the well cannot, of course, all be counted available for use. The amount will be materially reduced by friction in the pipes. Probably it will be necessary to allow 1,000 cubic feet at the well head to every stove. The highest charge now made in the State for stoves is $3.00 a month, which is about ten cents per 1,000 cubic feet. A well yielding 25,000 cubic feet per day would thus pay $75 a month, or $900 a year. If the cost of the well is less than $2,000, such a return would probably be safe. The well would in this case return the money spent in drilling it, with proper interest, in the course of three years, and it would also bear its share of the expense of distribution. Perhaps wells of this grade are as small as can be made safely remunerative for town supply. Single wells of such volume cannot be depended on for steam production to be used in driving large engines. Wells of 40,000 to 50,000 cubic feet, or aggregating this amount, would be as small as it would be safe to rely upon for such use where no great distance is to be traversed by the gas.

Approximate lower limits for profitable production may be found in the facts here given. With the strong desire to succeed in the novel search, most of the newly formed gas companies satisfy themselves for a time, at least, with returns which they would be willing to accept in no other line of investments.

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GEOLOGICAL MAP
OF
OHIO
BY
EDWARD ORTON, STATE GEOLOGIST.
Based on Newberry's Maps of 1869 & 79
TO ACCOMPANY
REPORT
ON OIL WELLS AND GAS WELLS
1885.
Trenton Limestone unproductive
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IND.
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